Final
Santa Ana Mountains Tecate Cypress (*Cupressus forbesii)* Management Plan

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EXECUTIVE SUMMARY

Orange County's Central and Coastal Natural Community Conservation Plan/Habitat Conservation Plan (NCCP/HCP) was established in 1996 to conserve sensitive plant and animal species on approximately 37,000 acres. Tecate cypress (*Cupressus forbesii*) is a rare endemic species restricted to several locations in southern California and northern Baja California. The northern most population of Tecate cypress occurs in the Santa Ana Mountains within the NCCP/HCP Central Reserve and receives regulatory coverage under the Plan. This population is threatened by too frequent wildfire. The Nature Reserve of Orange County (NROC) oversees monitoring and management of species within the NCCP/HCP and formed the Tecate Cypress Management Committee (TCMC) to develop a management plan for this species. The committee is composed of land owners, land managers and regulatory agencies with an interest in conserving Tecate cypress in the NCCP/HCP. This management plan was developed by NROC based upon the work of researchers from UC Berkeley and input from the TCMC.

The objectives of this management plan included determining the current distribution and demographic structure of the Santa Ana Mountains Tecate cypress population and using this data in ecological models to assess threats to persistence and to identify restoration sites for enhancing the population. The management plan includes a thorough review of Tecate cypresss and related species with information relevant to management. The plan documents changes in the historic extent of this species in the Santa Ana Mountains relative to fire history. Field studies conducted in spring 2009 delineated the current distribution, abundance and demographic structure of the population. Demographic models were then constructed to characterize population dynamics and to identify minimum conditions for persistence. The demographic models were linked to a model identifying spatial variation in fire risk and sensitivity analyses were conducted to predict population trajectories with different fire frequencies. Habitat modeling was employed to assess environmental relationships and identify candidate sites for restoration to enhance the current population. Knowledge gaps were identified and research priorities developed. Based upon the the current population status and ecological modeling results, montoring and management actions were formulated. Finally, a cooperative interagency management agreement was drafted to facilitate future monitoring and management activities.

Tecate cypress is adapted to a fire regime with fire return intervals of 30-40 years, a period sufficient for individuals within a stand to develop cones to ensure replacement. There have been six large fires affecting the population over the last 95 years. Based on 2009 surveys, it is estimated that the current poplation is distributed over 200 ha and consists of approximately 3,800 adult and 200 juvenile trees and thousands of seedlings. There is substantial variation in population structure, with fragmented and isolated refugia supporting reproductive adults in ravines and slopes and patchy areas of high seedling density interspersed with patches exhibiting little or no post-fire recovery. Many refugia with cone-bearing trees are located at the lower edge of the distribution where the probability of upslope recruitment is low. Over the last 20 years wildfires have significantly reduced the effective population size but have not significantly contracted the extent of the distribution. The structure of the current population is shaped by fire history, post-fire drought, site-specific habitat characteristics, and pre-fire stand age structure and density. The majority of the current population is composed of seedlings that will not reach maximum seed production for many years, putting the population at risk if there is a large wildfire in the stands during the next 20 to 30 years.

An assessment of fire risk indicates that areas where Tecate cypress currently occurs have similarly high burn susceptibilities. Field surveys identified isolated refugia associated with steep slopes and ravines. A size-based environmentally stochastic model identified key features of the Tecate cypress population affecting persistence. Current levels of cone and seed production would be adequate for self replacement (i.e., one seedling per reproductive adult every two years) if the population were connected and if recruitment occurred independently of fire events. However, the population is fragmented and there is little known about year-to-year recruitment in the absence of fire. When fire stochasticity is included in the model, Tecate cypress population growth declines under fire regimes with fire return intervals of less than 35 years. This indicates fire should be kept out of the stands for at least the next 30 years allowing individuals to achieve reproductive maturity and supply sufficient seed for replacement following the next fire event.

MaxEnt models were constructed to predict suitable habitat for adult and seedling Tecate cypress in the Santa Ana Mountains. The models predicted low habitat suitability for most of the study area outside the current range of Tecate cypress. Potential areas for establishment of Tecate cypress seedlings include north slopes at intermediate elevations with mild average annual temperatures (<13.5ºC), moderate precipitation (92-133 mm during the growing season), shallow soils (restrictive layers < 14 cm), a high percentage of sand (>50%), and low vegetation cover (<40%). Because the different variables incorporated within the models vary in resolution, it is recommended that predictions from single variable models also be assessed in selecting potential restoration sites. The habitat models are based upon an aggregated distribution of locations representing the current distribution of Tecate cypress in the Santa Ana Mountains and which are similar in environmental characteristics. If models were constructed with a broader sample of Tecate cypress locations representing the entire species range and greater variability in environmental conditions, it is likely that suitable habitat predictions would be less restrictive. It is unknown whether the current restricted distribution is due to environmental filters at the seedling establishment phase reflecting a true restriction to a particular area or is a result of low dispersal. Potential factors affecting seedling establishment and survival include soil characteristics, precipitation and soil moisture, and competition with shrubs. It is recommended that habitat modeling based upon the entire extent of the species distribution and experimental planting trials be implemented to further understand limiting environmental conditions for seedling establishment and survival. Priority areas for restoration were identified based upon seedling habitat suitability predictions combined with an analysis of fire risk during Santa Ana wind conditions.

The major threat to the Tecate cypress population in the Santa Ana Mountains is frequent, large wildfires. Other potential threats include drought, changing climate, air pollution, invasive plants, and human disturbance. The single most important thing that land managers can do to ensure the continued persistence of Tecate cypress is to reduce fire frequency. A number of strategic and tactical management recommendations were formulated to prevent and control fires. These include having the TCMC work with transportation agencies to implement fire-hardening measures (e.g., k-rails, concrete walls and hardscaping) along Highway 91, the 241 Toll Road and other major roadways adjacent to NCCP/HCP lands in the northern Central Reserve. The committee should also work with utility companies to reduce the risk of powerline ignited fires near the Tecate cypress population. The TCMC should coordinate with the Orange County Fire Authority to ensure fire roads are maintained to standards that allow access to the population during fire events. To coordinate management activities, the TCMC should meet annually with fire agencies to assess fire risk and preparedness and make recommendations for annual management activities. The committee should work with the owners of the proposed housing development at the base of Gypsum Canyon and the Anaheim Fire Department to develop fire prevention strategies. The TCMC should also coordinate with Orange County Fire Authority and Fire Watch patrols to prepare for red flag events and develop a public outreach program to educate people on fire prevention in the northern Santa Ana Mountains.

There are a number of actions that land managers can take to reduce fires in the the northern Santa Ana Mountains. These include prohibiting prescribed fires within the Tecate cypress population, controlling invasive weeds near roads and ignition hot spots, restoring flammable weedy areas to native shrubland in high risk fire ignition areas, restricting public access, and increasing vigilance and patrols during high fire risk conditions. Other actions including banning smoking on all reserve lands, prohibiting shooting and hunting, strictly enforcing bans on recreational off-road vehicle activity, and limiting public access to pullouts adjacent to the Central Reserve along Highway 91 and the 241 Toll Road.

The TCMC should develop a working committee with representatives of the fire agencies to develop a tactical fire plan for Tecate cypress stands. This plan would identify fire fighting strategies and techniques and provide guidelines for use of fire as a vegetation management or fire suppression tool only as absolutely necessary near the Tecate cypress population. During a fire event, NROC's designated lead resource advisor will coordinate with the Orange County Fire Authority to provide technical advice consistent with NROC's Fire Management Plan and the fire working committee recommendations. Following a fire in the Tecate cypress population the TCMC should make a field visit to assess fire impacts and formulate immediate remedial actions to protect the population. NROC and the TCMC will coordinate a post-fire population risk assessment to guide specific management actions for population recovery.

In addition to fire prevention recommendations, there are a set of management recommendations that focus on restoring and expanding the population to increase the likelihood that if there is a fire in the stands during the next 30 years, some individuals would survive to reproductive maturity and contribute to population recovery. There are gaps in our knowledge of Tecate cypress life history traits, environmental requirements for seedling establishment and growth, and specific restoration techniques. The management plan takes a two-phased approach to restoration, with Phase I focusing on filling these knowledge gaps and developing specific recommendations for selecting and prioritizing restoration sites, guidelines for seed collection, and best restoration practices. During this first phase, smaller scale planting trials will be implemented to gather needed data for refining restoration recommendations. Experimental trials are needed to determine the effects of soil, climate and vegetative cover on seedling establishment and growth and to evaluate whether suitable habitat is as restrictive as predicted by the habitat models. Specific restoration techniques should be tested for efficacy and cost, including planting seeds versus seedlings, different site preparation methods, and the use of supplemental water.

The goal of Phase II is to facilitate the long-term persistence of Tecate cypress in the northern Santa Ana Mountains by augmenting the population within its current distribution, re-establishing the population within the historic range, and expanding to new potentially suitable areas. The historic distribution can be divided into three strategic regions that are of high restoration priority. One region in the northern and northwestern flanks of Coal and Gypsum Canyon has good growing conditions with relatively low fire risk. A second region in Fremont Canyon has higher fire risk but potentially good growing conditions. The third area with low fire risk and relatively low habitat suitability includes high elevation areas in the Cleveland National Forest along the eastern side of the

Santa Ana Mountains. Further habitat modeling and understanding of environmental restrictions will inform identification of areas outside the current and historic distribution that are suitable for restoration.

This plan recommends that the northern Santa Ana Mountains Tecate cypress population be monitored for five years to establish year-to-year variability in cone production and evaluate seedling recruitment without fire. Monitoring methods should follow those used in the 2009 surveys. Once this baseline data is collected, the population should be monitored every five years to gather data consistent with that collected during the 2009 surveys (e.g., size and number of seedlings and adults, cones per adult, number of skeletons).

Contingency measures should be implemented in case of another fire in the Tecate cypress population within the next 20 to 30 years and in preparation for some other catastrophe such as emergence of a new disease pathogen or insect pest. Recommended measures include collecting seeds from the wild population on an on-going basis to store for use in a contingency situation and to provide for the restoration and expansion of the population. Seeds should be archived and stored to reduce impacts to seed viability. Seed banks should be maintained at two or three institutions. A nursery population should also be established to provide a source of seeds in an area removed from the wild population (e.g., within the urban core near the Central Reserve).

The draft Interagency Cooperative Management agreement is intended to facilitate conservation and management of Tecate cypress in the northern Santa Ana Mountains. It is a Memorandum of Understanding that has been drafted for review and approval by the participating land owners, land managers, and organizations responsible for overseeing conservation of Tecate cypress in the NCCP/HCP.

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1.0 INTRODUCTION

Orange County's Central and Coastal Natural Community Conservation Plan/Habitat Conservation Plan (NCCP/HCP) was established in 1996 to conserve sensitive plant and animal species on approximately 37,000 acres (County of Orange 1996). The Plan was developed by the County of Orange, the California Department of Fish and Game (CDFG), and the United States Fish and Wildlife Service (USFWS) to conserve multiple sensitive species and their natural habitats within a subregional Reserve System that allows for appropriate levels of growth and development. In addition to setting aside lands for conservation, the NCCP/HCP includes a long-term adaptive management program to protect species and habitats covered under the Plan. Wile the focus of the Plan is to conserve sensitive coastal sage scrub habitat, it also protects a habitat mosaic that includes chaparral, grassland, riparian, oak woodland and forest. The NCCP/HCP conserves and provides regulatory coverage for 39 plant and animal species across the Reserve System (Figure 1-1). The Nature Reserve of Orange County (NROC) is a non-profit corporation established to oversee implementation of monitoring and management activities within the NCCP/HCP. NROC coordinates monitoring and land management activities of public and private landowners within the Reserve System. Within this Reserve, only land uses that are compatible with habitat and wildlife preservation are allowed.

Tecate cypress (*Cupressus forbesii*) is a rare endemic species restricted to southern California and northern Baja California and is classified as a List 1B Species by the California Native Plant Society (http://www.cnps.org/cnps/rareplants/ranking.php). The northern most population of Tecate cypress occurs in the Santa Ana Mountains within the Reserve System and receives regulatory coverage under the NCCP/HCP. Tecate cypress is adapted to a fire regime with fire return intervals of 30-40 years, a period sufficient for stands to develop cones to ensure replacement. Too-frequent fires can cause the loss of adult stands and threaten persistence of the population. Recent fires (2002 and 2006) have burned through the population putting it at risk of local exinction in future fires. To address this risk, a Tecate Cypress Management Committee (TCMC) composed of representatives from various government agencies, landowners and managers formed to develop a management strategy for this species. NROC has taken the lead in developing a management plan for the Santa Ana Mountain population of Tecate cypress with financial assistance from CDFG and participation and review by the TCMC.

Agencies, land owners and land managers participating in the TCMC include:

- California Department of Fish and Game
- Chino Hills State Park
- Irvine Company
- Irvine Ranch Conservancy
- Nature Reserve of Orange County
- Orange County Fire Authority
- Orange County Parks
- The Nature Conservancy
- United States Fish and Wildlife Service
- United States Department of Agriculture Cleveland National Forest, Trabuco Ranger District

- University of California, Berkeley

Drs. Suding and Rodriguez-Buritica from the University of California conducted extensive surveys and ecological modeling to provide the basis for management recommendations. The Plan consists of a description of the historic and current status of Tecate cypress within the Reserve System, a fire risk assessment linked to dynamic population models, a habitat assessment and recommendations for managing fire risk, restoration and contingencies. Finally, there is a section addressing an interagency cooperative agreement among landowners and managers.

Figure 1-1. Orange County's Central and Coastal NCCP/HCP Reserve System.

Tecate Cypress Management Plan Goals and Objectives

The goal of this Plan is to develop a long-term strategy for the protection and management of Tecate cypress within the Santa Ana Mountains in order to ensure the continued persistence of this species.

Specific objectives in developing this Plan include:

- Conduct a thorough literature review of Tecate cypress and related species to document their life history characteristics, historic distribution and to obtain other information relevant to the management of this species
- Conduct field surveys to determine the current distribution, population status, reproductive status and replacement potential of Tecate cypress in the Santa Ana Mountains
- Identify potential threats to Tecate cypress in the Santa Ana Mountains
- Integrate field measurements of current population structure, replacement capability and reproductive potential into a demographic model to characterize population dynamics of the Santa Ana population and identify minimum conditions for population persistence
- Conduct a fire risk assessment, including modeling fire behavior, to identify spatial variation in fire risk for the Tecate cypress population in the Santa Ana Mountains
- Link the fire and demographic models to conduct a sensitivity analysis and predict population trajectories with different fire frequencies
- Determine management practices to protect the existing population from potential threats, including specific recommendations based upon the fire risk assessment and demographic modeling
- Determine candidate sites for restoration and enhancement of the existing population using habitat modeling in conjunction with an assessment of the current and historic distribution of Tecate cypress in the Santa Ana Mountains
- Determine restoration and contingency measures to enhance the current population in the Santa Ana Mountains
- Identify knowledge gaps and determine research priorities to address these gaps
- Develop a cooperative interagency management agreement that specifies the roles and responsibilities of Committee members in jointly managing the Santa Ana Mountain Tecate cypress population

2.0 EXISTING CONDITIONS

Tecate cypress is one of twelve new world cypress species that occur in California. Currently, this species is considered vulnerable because there are only a few small and poorly connected populations (IUCN, 2006). Tecate cypress grows between 200-1200 meters above sea level and is distributed in four groves in southern California and several disconnected stands in northern Baja California. (Figure 2-1). The purpose of this section is to provide a detailed description of the current status of the northern Tecate cypress population. This population occurs in the northern Santa Ana Mountains, in an area where jurisdiction is shared by public and private agencies, including the Irvine Ranch Land Reserve, the California Department of Fish and Game and the Cleveland National Forest. Here, we focus on three aspects of this population. First, we present an updated distribution map of live Tecate cypress trees and a brief discussion of changes in the historical distribution in this area. Second, we describe areas where this species grows in terms of current and past densities and structure. Finally, we provide a detailed characterization of areas with cone-bearing Tecate cypress and a discussion of the implication of these sites on future conservation and restoration plans.

Distribution of Tecate Cypress

Tecate cypress forms four distinctive stands in Southern California with scattered trees along a 150 km strip in the coastal foothills of Baja California (Minnich 1987). Wolf (1948a) provided one of the first formal descriptions of U.S. populations, while Minnich (1987) described locations of Tecate cypress in Mexico. The four stands in California are located in the Santa Ana Mountains in Orange County and in Guatay, Otay, and Tecate Mountains in San Diego County. Outside these areas, there are several recorded occurrences of this species in botanical collections dating back to 1872 (Consortium of California Herbaria, 2009). Table 2-1 summarizes the main characteristics of the four U.S. stands, following the original description by Wolf (1948a) and subsequent descriptions by Armstong (1966), Griffith and Critchfield (1972), Stottlemeyer and Lathrop (1981), Spenger (1985), and Dunn (1985 and 1986). Figure 2-1 illustrates the location of the four main populations, areas where scattered individuals grow in Baja California, and areas with point locations from botanical collections.

The Otay mountain population is the largest population of the species, with an extent of 2400 ha (Dunn 1986). Although most of the population burned in 2003, successful recruitment has been recorded (DeGouvain and Ansary 2006). The Tecate peak population is much smaller, and after a 1985 fire this population shrank from 105 to 30 ha (Dunn 1985). These two populations constitute the southern limit of Tecate cypress in the United States, although both stands extend further south into Mexican territory (Griffith and Critchfield 1972). The population on Guatay Mountain is the smallest with an area of 19 ha and has not burned in 100 years (Dunn 1986, DeGouvain and Ansary 2006). The Sierra Peak population in the Santa Ana Mountains, the focus of this report, is intermediate in size at 400ha. There are no reports of well constituted stands in Baja California (Minnich 1987).

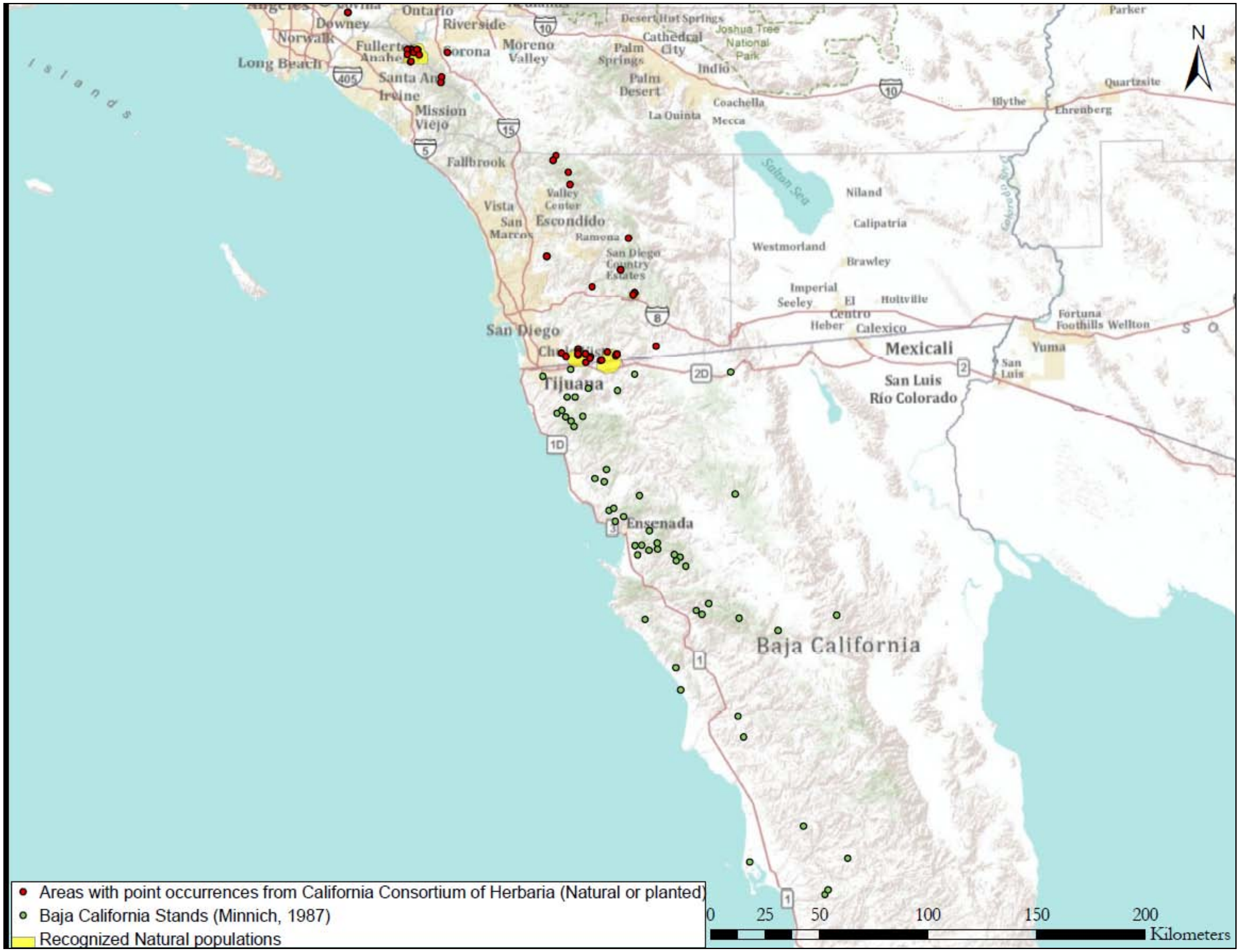

Figure 2-1. Distribution of Tecate cypress populations. Distributions are based on descriptions of Tecate cypress stands reported since 1948, and herbaria records (Consortium of California Herbaria 2009). North/south directions are indicated by ±; north corresponds to the top of the cross.

Table 2-1. Description of natural populations of Tecate cypress in southern California and Baja California, Mexico. Source for each attribute description is in parenthesis.

Stand Name	Location	County	Elevation	Extent	Soil	Associated vegetation
Guatay Mountain	Northern slope of Guatay Mountain; 17 miles from Potrero Creek (Griffith and Critchfield 1972)	San Diego County	1080-1440 masl	19 ha (47 acres)	Soil derived from fine-grained reddish granite with prevalent A0 and A1 horizons (Armstrong 1966). The Guatay Mountain Gabbroic pluton includes amphibole gabbro, gabbro, and olivine gabbro. The soils are well-drained and classified as Las Posas series (Cheng 2004)	*Arcostaphylos glandulosa, Ceanothus crassifolius, Quercus turbinella, Quercus agrifolia, Cercocarpus betuloides, Quercus dumosa, Adenostoma fasciculatum* (Armstrong 1966)
Otay Mountain		San Diego County	220-1040 masl	More than 3.2 km wide (Armstrong 1966). 2400 ha (5930 acres; Dunn 1986)	Soil from volcanic material with interbedded clastic sedimentary rock. Cypress mostly on metavolcanic rocks in soils with lack of organic material (Armstrong, 1966). Soils with higher nutrient content and three times the organic matter than soil where associated vegetation occurs (Dunn, 1986)	*Chamaebatia australis, Ceanothus otayensis, Arctostaphylos otayensis, Pickeringia montana, Arctostaphylos glandulosa, Adenostoma fasciculatum, Ceanothus tomentosus, Eriodictyon trichocalyx, Malosma laurina, Rhus ovata, Lepechinia fragrans, Heteromeles arbutifolia, Dendromecon rigida, Yucca whipplei, Lathyrus laetiflorus, Zigadenus fremontii* (Armstrong 1966)
Tecate Mountain	5 miles east from Otay Mountain, in the Tecate Peak-Potrero Creek area (Griffith and Critchfield 1972)	San Diego County	510-900 masl (Armstrong 1966)	105 ha before 1985; 30 Ha afterwards (74 acres; Dunn, 1985)	Soil is derived from granite (Armstrong, 1966)	*Adenostoma fasciculatum, Salvia mellifera, Ceanothus crassifolium Ceanothus tomentosus, Rhamnus tomentella, Arctostaphylos glandulosa, Nolina cismontane, Yucca whipplei, Rhus ovata, Romneya coulteri, Eriodictyon crassifolium*

Table 2-1 continued. Description of natural populations of Tecate cypress in southern California and Baja California, Mexico. Source for each attribute description is in parenthesis.

Stand Name	Location	County	Elevation	Extent	Soil	Associated vegetation
Sierra Peak/ Santa Ana Mountains	Northwest slope of Sierra Peak with a few individuals along the Santa Ana River. (Griffith and Critchfield, 1972)	Orange County	170-706 masl	400 ha (1000 acres) in 1966 (Armstrong 1966); same area in 1985 (Spenger 1985)	Silverado soil formation (Spenger, 1985). Trees on eroded clay, shales, sandstones, and conglomerates (Vogl 1976). Cieneba-Anaheim-Soper Asociation (SSURGO, 2009) with pH ranging from 4.2 to 6.5, very low in nitrogen and with 28-30% clay (Stottlemeyer and Lathrop, 1981).	*Adenostoma fasciculatim, Ceanothus crassifolius, Lepechinia cardiophylla, Erodictyion crassifolim, Arctostaphylos glandulosa, Yucca whipplei, Noina parryi, Salvia mellifera, Malosma laurina, Heteromeles arbutifolia, Cercocarpus betuloides, Thamnus crocea, Eriogonum fasciculatum, Mimulus longiflorus, Artemisia californica, Helianthemum scopariu, Eriophyllum confertiflorum, Elymus triticoides.* (Armstrong 1966)
Baja California	Along Cerro Bola range, especially south between Cerro San Felipe and Cañada el Golpe. Interior outliers at Cerro Grande 10 km south from Tecate. Other cluster south and east from Ensenada, from Rancho de la Cruz to Cerro los Pinos. To the south isolated populations occur in costal canyons with *Pinus muricata.* Significant forest on Guadalupe Island (Minnich 1987).	Baja California, Mexico	50-450 masl (Armstrong 1966)	150 km along the coast (93 miles; Minnich 1987)	Alistos and Rosario formation; some trees growing on granodiorites (Dunn 1986)	

Extent of the Sierra Peak/Santa Ana Mountains Population

The Santa Ana Mountains population is the northern-most stand of Tecate cypress and the second largest with approximately 400 ha reported in 1985 (Armstrong, 1966, Spenger 1985). Until 2000, this population extended between the northwest slopes of Gypsum Canyon and northeast Coal Canyon, with a few scattered individuals growing along the ridge dividing Gypsum and Fremont Canyons (Figure 2-2). The Santa Ana population falls under the jurisdiction of three different entities. The western part of the population is within the Irvine Ranch Land Reserve. The eastern portion is on state and federal public lands including the southern most area of Coal Canyon Ecological Reserve under jurisdiction of the California Department of Fish and Game and the northeast portion within the Cleveland National Forest.

The Santa Ana Mountains population grows on intermediate to steep slopes dominated by rocky outcrops, with soils predominately in the Sieneba-Anaheim association (SSURGO 2009). In the specific areas where Tecate cypress grows, soils have a pH ranging from 4.2 to 6.5, are very low in nitrogen, and are composed of 28-30% clay. These soils are more acidic and nitrogen poor than soils in other locations where Tecate cypress occurs. Within the Santa Ana Mountains, soil characteristics where Tecate cypress grows do not differ from adjacent chaparral areas (Stottlemeyer and Lathrop 1981). Tecate cypress grows in dense stands or intermixed with chamise-chaparral vegetation. Based on spring 2009 observations, the shrub community in this area is dominated by chamise (*Adenostoma fascilulatum*), Yerba Santa (*Eriodictyon crassifolium*), and at least two lilac species (*Ceanothus* sp.). Other common species include manzanita (*Arctostaphylos glandulosa*), black sage (*Salvia mellifera*), Lord's candle (*Yucca whipplei*), and chaparral beargrass (*Nolina cismontana*). We detail habitat associations in more detail in the Habitat Assessment (Section 4).

The Tecate cypress population in the Santa Ana Mountains was first reported in 1872 by James G. Cooper (Griffith and Critchfield 1972) and fully described by Wolf (1948a). In 1948 and 1967 two large fires burned the entire population (Table 2-2). Nevertheless in 1972, Griffith and Critchfield reported a population extent that was consistent with past reports. They mapped the four populations in the U.S. and detailed distributions of stands in San Diego County (Table 2-1). In addition to the main stand, Griffith and Critchfield reported several individuals growing along Santa Ana Canyon, although they did not provide specific locations.

Stottlemeyer and Lathrop (1981) were the first researchers to distinguish between areas with low and high Tecate cypress densities. They described eleven areas with high densities along the ridge between Gypsum and Coal Canyons, on northeast and northwest gentle slopes (Figure 2-3). Because of the low resolution of this description, the area delineated by Stottlemeyer and Lathrop does not include trees growing on the southwest slope draining into Fremont Canyon, or lower areas closer to Gypsum Creek. These areas had large adult live trees in 1987.

Harmswoth Associates (2007) provided the most recent and detailed description of the Santa Ana Mountains population. Harmsworth Associates mapped the population in 2000 and subsequently described the area after the 2002 and 2006 fires. They found that Tecate cypress comprised about 243 ha in 2000. Discrepancies from previous reports illustrate differences in precision of area estimates due to variation in sampling of patchy areas. During our literature review and our fieldwork, we did not find any evidence suggesting that the extent of this population shrank between 1985 and 2000, although densities could have changed substantially. Figure 2-3 illustrates the

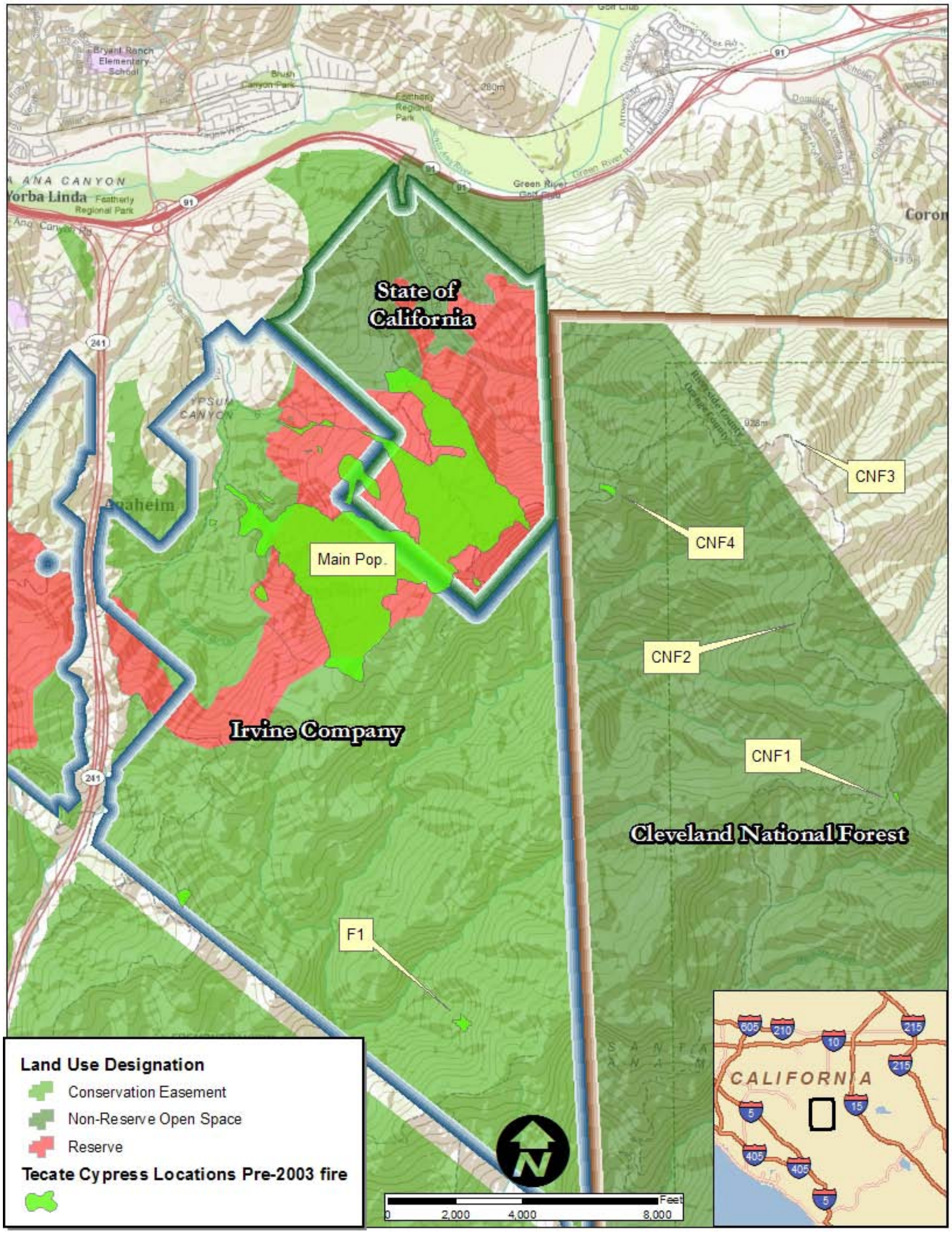

Figure 2-2. Overview of Tecate cypress Santa Ana Mountains population. This map depicts areas where Tecate cypress has been previously reported and where it has been planted. The main population falls on the northwest and northeast slopes of the northern Santa Ana Mountains. F1, CNF1, CNF2, and CNF4 refer to satellite natural stands in Fremont Canyon and the Cleveland National Forest; CNF3 refers to the northern most of two planted stands in the Cleveland National Forest. The study area is located in the USGS Black Star Canyon 7.5 minute quadrangle.

Table 2-2. Fires in the Santa Ana Mountains study area since 1914. Fires larger than 2,000 acres (809 ha) with a portion of their perimeter within the Tecate cypress study area. The percent of the population that burned is estimated using the 2000 distribution reported by Harmsworth and Associates (2007).

Fire Name	Date	Population Area Burned	Total Acreage Burned
No Name	1914	Western border, approximately 20%	14,830
Green River	1948	100%	41,285
Paseo Grande	October 29, 1967	100%	39,872
Gypsum	October 9, 1982	Western side, approximately 75%	19,986
Green	February 9, 2002	Eastern side, approximately 90%	2,234
Sierra Peak	February 6, 2006	Upper, lower, and western borders, approximately 20%	10,506

distribution of Tecate cypress in 2000 based on the mapping provided by Harmswoth Associates and our own observations of dead tree locations in 2009.

There are several small stands of Tecate cypress in the Cleveland National Forest. Stottlemeyer and Lathrop (1981) described two areas with planted cypress. These areas are along the truck road connecting Corona with Silverado and running through the Cleveland National Forest. The first location is close to Bedford Peak and is a small stands of 25 individuals that were planted in the 1960's by the Izaak Walton League (Mary Thomas pers. com.). This stand burned in the 2006 fire. The second area is close to Sierra Peak and has 20 adult cypresses also planted by the Izaak Walton League (CNF3 in Figure 2-2). In addition to these two plantations, we also recorded two more areas with naturally occurring cypress along the same road (CNF1, CNF2 and CNF4 in Figure 2-2).

Current Status of the Santa Ana Mountains Tecate Cypress Population

One of the main objectives of this study is to determine the current status of the Santa Ana Monuntains Tecate cypress population, especially considering the effects of the last two fire events. To this end, we designed a survey to answer two specific questions:

1. How do densities of seedlings and skeletons and pre- and post-fire population structure vary throughout the area where Tecate cypress was originally described?

2. What is the current status of the Santa Ana Tecate cypress population in terms of density of survivors and locations of active seedling recruitment and live cone-bearing trees?

Methods

Our study area comprises the entire stand of Tecate cypress located along the ridges and slopes of Coal, Gypsum, and Fremont Canyons (Figure 2-2). It also includes the isolated natural stand in Fremont Canyon (F1 in Figure 2-2), and the areas where Tecate cypress was planted in the Cleveland National Forest (CNF3 in Figure 2-2) or occur naturally in isolated patches of

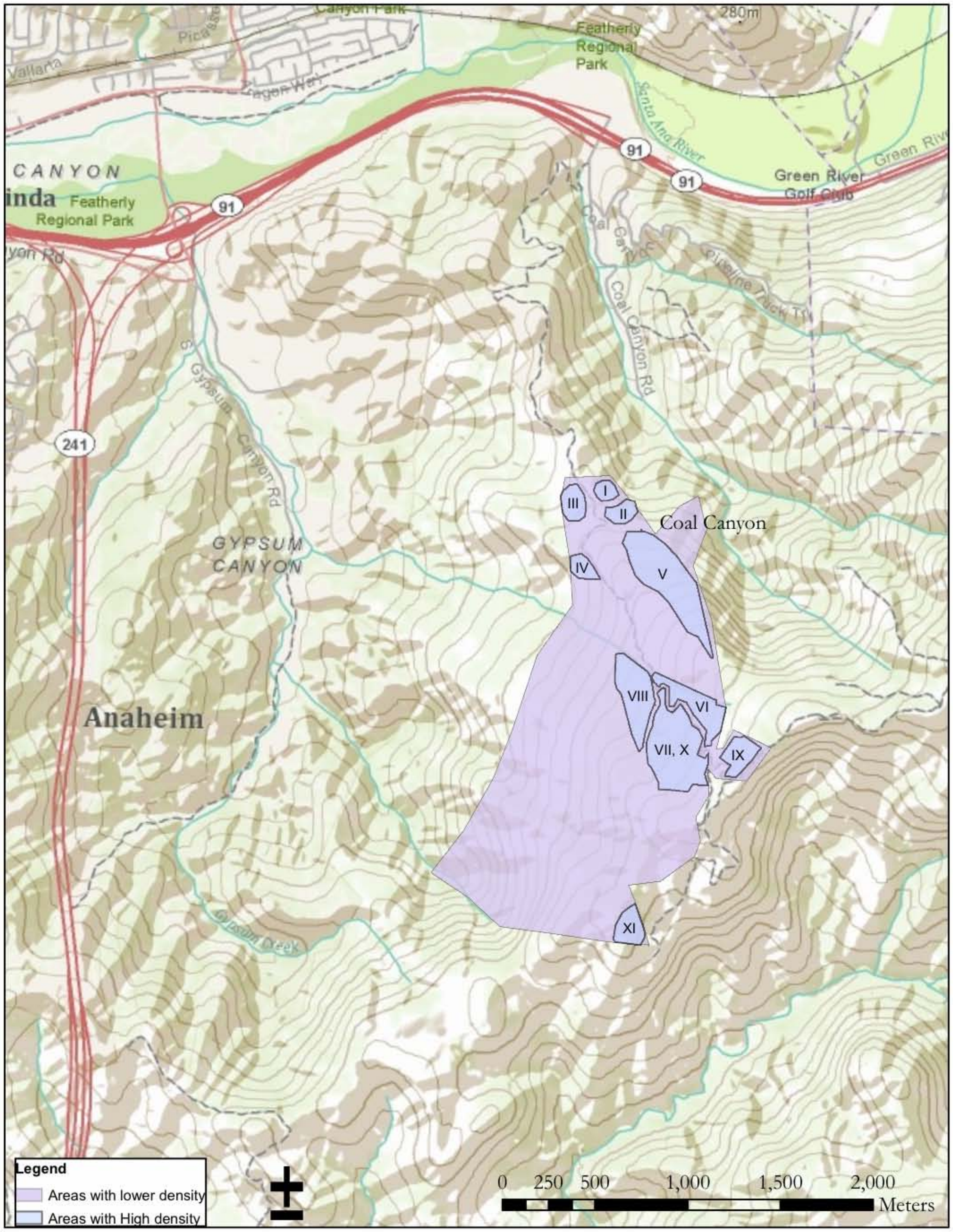

Figure 2-3. Distribution of Tecate cypress in the northern Santa Ana Mountains in 1981. This figure is based upon the first published map (Stottlemeyer and Lathrop 1981) that distinguishes areas of high (numbered polygons in light blue) and low density (large polygons in violet) Tecate cypress. North/south directions are indicated by ±; north corresponds to the top of the cross. The study area is located in the USGS Black Star Canyon 7.5 minute quadrangle.

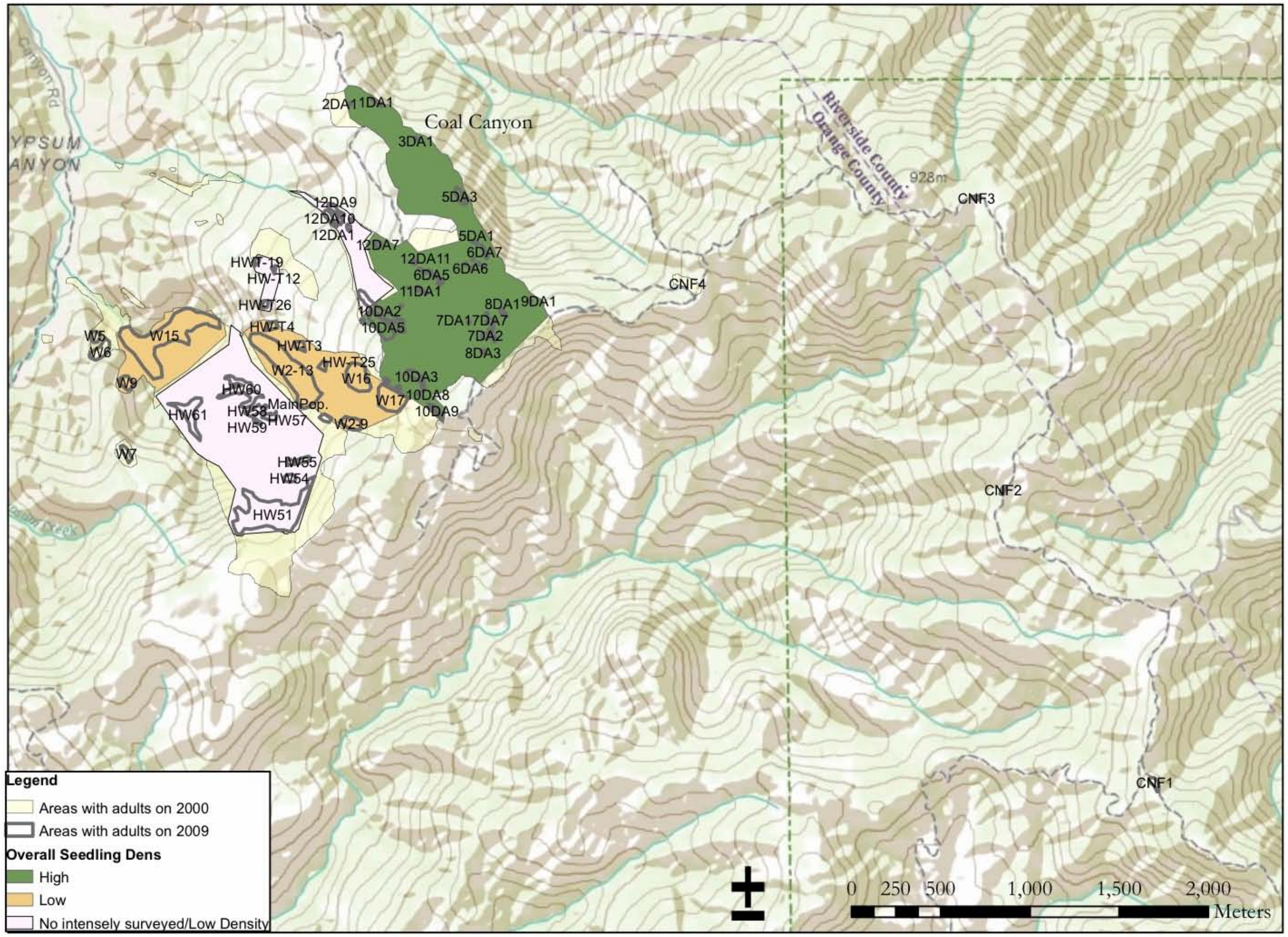

Figure 2-4. Overview of the main Tecate cypress stand in the northern Santa Ana Mountains. Areas occupied by Tecate cypress in 2000 are based on Harmsworth Associates (2007) and on areas with live adults in 2009. Some areas previously reported by Harmswoth were not re-visited during the 2009 census. These areas are indicated with the prefix HW. All other areas on Irvine Ranch Land were named using a prefix W. The first two digits in the name of refugia along Coal Canyon Ecological Reserve correspond to the number assigned to the strata. Areas with high and low density of seedlings in 2009, and areas not visited during 2009 surveys are shown. Areas with live adults in 2009 are labeled as in Table 5. North/south directions are indicated by ±; north corresponds to the top of the cross. The study area is located in the USGS Black Star Canyon 7.5 minute quadrangle.

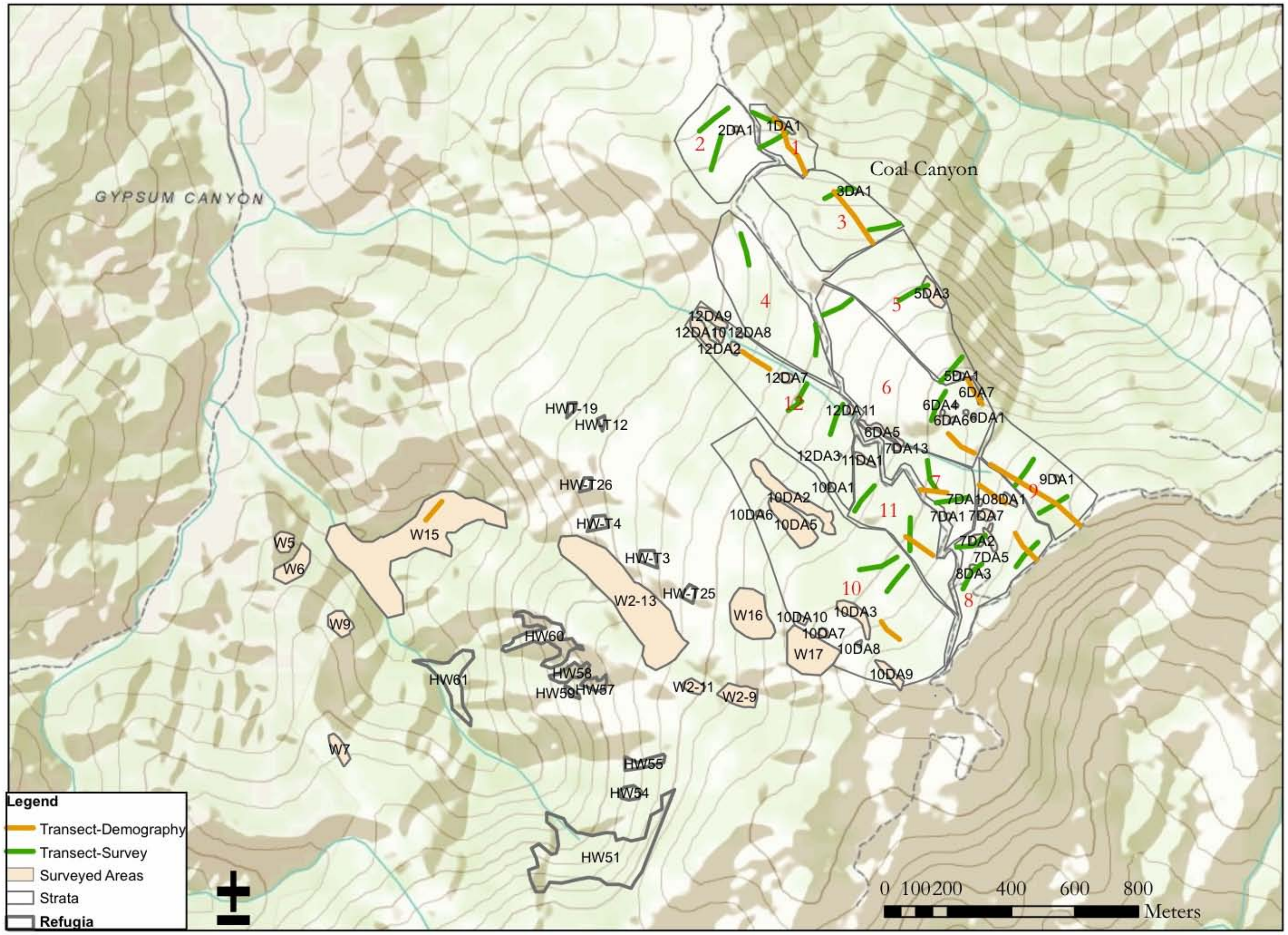

Figure 2-5. Transects and areas sampled from March to April 2009 for Tecate cypress in the northern Santa Ana Mountains. Numbered polygons correspond to strata used to characterize overall variation in Tecate cypress density (numbers in red). We counted seedlings and adults along 24 transects running perpendicular to the main slope (Transect-Survey; green). To describe the pre- and post-fire population structure, we used 15 additional transects running parallel to the main slope (Transect-Demography; orange). We also characterized areas that currently have live adults (Refugia) in terms of average size of trees and overall structure of the patch; these are the labeled polygons. North/south directions are indicated by ±; north corresponds to the top of the cross. The study area is located in the USGS Black Star Canyon 7.5 minute quadrangle.

very few individuals (CNF1, CNF2 and CNF4 in Figure 2-2). A detailed illustration of the main stand is provided in Figure 2-4.

In order to address our specific questions we conducted a census between March and June 2009 using three different methodologies. To describe variation in densities across the landscape, we selected twelve strata based on strong topographical features such as ridges, ravines and roads (numbered polygons in Figure 2-5). Within each of these twelve strata, we counted Tecate cypress seedlings and skeletons along two randomly located transects of 100 m each running perpendicular to the main slope (we refer to these as Survey Transects in Figure 2-5). Thus, we counted Tecate cypress adults and seedlings along 24 transects sparsely distributed in the Coal Canyon Ecological Reserve along the eastern portion of the main stand. For each transect, we also estimated the main dominant plant species and percent bare ground. In order to characterize variation in population structure prior to the most recent fires, we counted and classified all skeletons along 15 additional 100 m transects within the corresponding strata and parallel to the main slope (we refer to these as Demography Transects in Figure 2-5). We only included strata for which we detected high skeleton density in survey transects; this excluded 3 out of the 12 original strata. All individuals within these transects were classified as live or dead and categorized by size. Size categories were defined as a combination of a height and diameter classes (Table 2-3). This methodology provided a detailed description of pre-fire population structure, which allows a better estimation of potential recovery value after fire than density. This method also allows us to identify areas with better growing conditions for seedlings.

In addition to these two sets of transects, we characterized areas with live adult trees that did not burn in the last two fires, which we refer to as refugia for the remainder of this document. Within each refugium we counted and classified all individuals and counted cones for a subsample of individuals. This method allowed us to assess the current recovery potential of this population in case of an imminent fire. We completed the description of the population by counting and classifying skeletons of extirpated patches in Fremont Canyon and the southwest corner of the Cleveland National Forest, just below Sierra Peak, as well as small stands along the road in Cleveland National Forest (F1 and CNF 1-4 in Figure 2-2).

Table 2-3. Combination of height and diameter classes used to define final demographic size classes. Final classes are indicated in the central portion of the table and group together different combinations of height and diameter classes. Initial height and diameter classes are modified from classes used by DeGouvain and Ansary (2006).

	Diameter Classes						
Height Classes	1 (< 0.5cm)	2 (0.5-2 cm)	3 (2-4.5 cm)	4 (4.5-7 cm)	5 (7-15 cm)	6 (15-30 cm)	7 (> 30 cm)
1 (< 0.5 m)	1	1	2				
2 (0.5-1m)	1	2	2				
3 (1-1.5 m)		2	3				
4 (1.5-2 m)		3	3	4	5		
5 (2-3 m)		3	4	4	5		
6 (3-5 m)		4	4	5	5	6	
7 (5-10 m)					6	6	7
8 (>10 m)						7	7

Results

The current population density of the Santa Ana population of Tecate cypress is estimated to be approximately 4,000 adults and 200 saplings (pre-cone bearing trees) with a seedling density of 12,642 seedlings/ha. There are 75 patches with live adults (Table 2-4), and a substantial area (60.6 ha; sum of Strata 1,3,5-9, and 11) with high densities of seedlings (1.49-3.49 seedlings/m^2; Table 2-5).

Spatial Variation of Seedling and Skeleton Densities in Coal Canyon Ecological Reserve

In general, recruitment is restricted to the eastern most portion of the population, which corresponds with the Coal Canyon Ecological Reserve (Figure 2-4). In particular, within this section, high densities of seedlings occur at low elevations on the slope draining towards Coal Canyon and at higher elevations on the eastern slope draining towards Gypsum Canyon. Very low seedling densities were detected throughout the western section of the distribution, which corresponds to the Irvine Ranch land. This latter area burned at least four times in the last 95 years and a major portion burned five times (see "Recent Changes in Population Extent Due to Fire", below). Table 2-5 summarizes the characteristics of each strata based on tree counts in the Survey Transects.

Another way to assess recruitment potential in different areas is to look at the seedlings to skeleton (former adult) ratio in areas that have burned. We refer to this relative measure as a recovery value, as it indicates the amount of seedlings that replaced each adult. Areas with high recovery values would be those where many seedling recruits replaced each adult; this could be due to high viable seed production per adult, optimal seedling establishment conditions or low seedling mortality. In contrast, areas with low recovery values would be areas where adults may not even be able to replace themselves with a seedling. Areas differed markedly in their recovery. In our survey we found that areas with high recovery values showed different seedling and adult density combinations (Figure 2-6). Figures 2-7a, b and Table 2-5 illustrate absolute density and skeleton densities, as well as seedling per skeleton ratios. We found the highest proportion of seedlings per skeleton in Stratum 1 (low elevation, northeast slope of the Gypsum-Coal Canyon ridge) due to the large seedling density and low skeleton counts. Strata 8 (high elevation) and 6 (intermediate elevation) were also areas with higher counts of seedlings relative to skeletons. Stratum 2 (low elevation, west of Gypsum-Coal canyons ridge) also had high recovery values but very low seedling and adult counts. There were also some areas that had high adult densities but moderate seedling recruitment (e.g. Stratum 11 at a high elevation east of the ridge between Coal and Gypsum Canyons). In general, areas with high recovery values correspond to areas burned in 1967 and 2002, whereas areas with low recovery values burned in 1967, 1982, and 2002.

Chamise, yerba santa, and chaparral beargrass were by far the most abundant species in the area and the percentage of bare ground varied considerably among strata (Tables 2-5 and 2-6). Field observations suggest upper elevation areas have higher bare ground percentages and sparser vegetation of lower stature (Strata 5,6,9 and upper portions of Strata 8 and 10). On the other hand, lower sections of Strata 10-12 supported denser and larger vegetation. Despite this observation, we could not capture this trend with our transect data, illustrating the spatial heterogeneity in vegetation coverage at the strata level. Although dominant vegetation and percent bare ground did not show a clear pattern with respect to seedling and skeleton densities, our field observations suggest that areas with low seedling and low skeleton densities occur at lower elevations with less bare ground and taller vegetation (Figure 2-6).

Table 2-4. Characterization of areas with live Tecate cypress trees. The location and extent of these areas is illustrated in Figure 2-9. Density and average size of Tecate cypress is for trees in areas that escaped recent fires (refugia). The average cone count is estimated for a subsample of at least 5 adults per stratum.

Area	Source	Refugium ID	Adult Count	Sapling Count	Located in Ravine	Average Adult Height	Average Adult Diameter	Average Cone Count
Coal Canyon Reserve	This Project	1DA1	8	0	No	4.80	11.33	285.00
		2DA1	0	0	No			
		3DA1	1	0	No	2.50		
		5DA1	25	30	No	2.03	3.72	24.55
		5DA2	1	25	No	1.75		
		5DA3	5	0	No			
		6DA1	9	0	No	2.23	3.50	8.50
		6DA2	3	0	No			
		6DA3	2	0	No	2.50		
		6DA4	11	0	No	2.50		
		6DA5	56	2	Yes	6.05	9.80	142.92
		6DA6	27	1	No	3.16	3.68	11.32
		6DA7	19	0	No	2.50		
		7DA1	5	0	No	3.30	7.40	95.20
		7DA10	19	1	No	2.66	6.28	
		7DA13	69	18	No	1.91	2.12	
		7DA2	51	1	Yes	3.49	3.80	52.74
		7DA4	15	0	No	3.12	5.21	38.00
		7DA5	93	0	No	3.75	5.55	111.11
		7DA7	49	6	No	2.90	4.94	56.50
		8DA1	115	0	Yes	3.65	4.75	43.93
		8DA3	20	0	No			
		9DA1	18	1	No	2.48	3.56	2.87
		10DA1	5	0	No	4.18	6.80	
		10DA10	1	0	No	3.50		
		10DA2	180	3	Yes	4.29	8.40	166.40
		10DA3	30	0	No			
		10DA5	71	0	No	4.54	10.55	65.10
		10DA6	9	0	No	2.85	5.17	57.67
		10DA7	1	0	No			
		10DA8	1	0	No	3.00		
		10DA9	10	0	No	3.50		
		11DA1	56	3	No	2.93	5.10	34.24
		12DA1	9	0	No	3.87	6.11	5.11
		12DA10	21	0	Yes	5.50		
		12DA11	0	0	Yes	6.00	20.00	
		12DA2	14	0	No	3.92	7.77	1.27
		12DA3	1	0	No			
		12DA7	36	0	No	3.48	5.12	8.33
		12DA8	2	0	Yes	4.50		
		12DA9	20	0	Yes	4.50		
Cleveland National Forest	This project	CNF1	4	0	No	4.50	25.00	
		CNF2	5	0	No	3.50	20.00	
		CNF3 (Planted)	23	0	No	4.50	20.00	
		CNF4	18		No	5.67	25.18	299.80

Table 2-4 continued. Characterization of areas with live Tecate cypress trees. The location and extent of these areas is illustrated in Figure 2-9. Density and average size of Tecate cypress is for trees in areas that escaped recent fires (refugia). The average cone count is estimated for a subsample of at least 5 adults per stratum.

Area	Source	Refugium ID	Adult Count	Sapling Count	Located in Ravine	Average Adult Height	Average Adult Diameter	Average Cone Count
Cleveland National Forest/ Silverado Canyon	This project	SC1 (Planted)	25	0	No			
Irvine Ranch	This project	W5	40	0	No	3.50	6.50	
		W6	0	0	Yes	4.00		
		W7	10	0	No	3.50		
		W9	40	0	No	6.56	11.80	
		W15	2000	0	Yes	6.66	9.70	54.00
		W16	30	20	No	4.00		
		W17	25	18	No	4.00		
		W2-9	10	4	Yes	8.30	16.00	
		W2-11	2	0	No	3.47	3.71	
		W2-13	211	2	No	3.30	6.50	
Irvine Ranch/Fremont Canyon	This Project	F1	67	26	Yes	5.62	14.23	
Irvine Ranch	Harmsworth Associates	HW51	2		No			
		HW54			No			
		HW55			Yes			
		HW57			No			
		HW58			No			
		HW59			No			
		HW60			No			
		HW61			Yes			
		HWT12	5		No			
		HWT19	15		No			
		HWT25	2		No			
		HWT26	1		No			
		HW-T3	8		No			
		HW-T4	8		No			

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Table 2-5. General characteristics of Tecate cypress sampled areas in the Coal Canyon Ecological Reserve. The eastern side of the population located in the Coal Canyon Ecological Reserve was divided into 12 strata according to elevation and topographic features. Within each strata we quantified the mean (± Standard Error) number and density of skeletons and seedlings, the percentage of bare ground and identified the most abundant plant species along the transect. Plant codes are listed in Table 2-6.

Stratum	Area (m^2)	Estimated Seedling Density (indiv/m^2)	Estimated Skeleton Density (indiv/m^2)	Estimated Number of Seedlings	Estimated Number of Skeletons	Estimated Number of Seedling/ Skeletons	Estimated Percent Bare Ground	Estimated Age when Burned in 2002	Dominant Plant Species
1	24,867.54	3.49 (±0.04)	0.37 (±0)	86614 (±186.76)	9,362 (±36.11)	9.25	10.00	35	ERCA>Ceanothus sp>NOCI>ADFA
2	63,676.37	0.02 (±0)	0.01 (±0)	1,272 (±2.82)	636 (±1.41)	2.00	32.22	20	NOCI>ERCA>ADFA
3	80,279.66	2.09 (±0.01)	0.69 (±0.01)	167,819 (±53.07)	55,539 (±49.1)	3.02	32.00	35	Ceanothus Sp>NOCI>ERCA>ADFA
4	90,381.26	0.01 (±0)	0	903 (±1.41)	0	0.01	25.00	20	ADFA>NOCI>SAME
5	96,646.36	1.48 (±0.02)	0.78 (±0.03)	143,451 (±81.31)	75,348 (±97.58)	1.90	20.00	35	ADFA>ERCA>SAME>YUCCA
6	146,765.67	1.81 (±0.03)	0.89 (±0.01)	265,527 (±143.24)	130,563 (±68.59)	2.03	31.50	35	ADFA>SAME>ERCA
7	43,409.35	1.64 (±0.01)	1.60 (±0.03)	71,393 (±78.88)	69,657 (±147.7)	1.02	27.00	35	ADFA>ERCA>SAME>HESC
8	82,934.22	7.56 (±0.38)	2.18 (±0.01)	626,724 (±1083.84)	181,344 (±68.68)	3.46	30.00	35	ERCA>Ceanothus sp>ADFA
9	62,277.32	1.6 (±0.03)	1.37 (±0.02)	99,983 (±132.85)	85,726 (±102.38)	1.17	21.00	35	ERCA>ADFA>Ceanothus Sp
10	287,215.84	0.87 (±0.03)	0.88 (±0)	150,062 (±72.08)	254,890 (±31.58)	0.98	35.79	20	ERCA>ADFA>HESC
11	68,932.27	2.42 (±0.05)	1.74 (±0.04)	167,197 (±188.68)	119,886 (±155.25)	1.39	16.00	20-35	Ceanothus Sp>ERCA>ADFA
12	114,624.91	0	0.43 (±0.02)	573 (±0.50)	49,851 (±63.28)	0.01	12.50	20	ADFA>SAME>Ceanothus Sp
Total population		1.26	0.87	1,468,347 (±350012.80)	101,1837 (±155860.13)				

Table 2-6. Common plant species in the Northern Santa Ana Mountains study area. The code column corresponds with species abbreviations used in Table 2-5 to characterize the dominance of each species. This list originated from 24 census plots and 15 demographic transects across the eastern portion of the study area.

Species Scientific Name	Common Name	Family	Code
Adenostoma fasciculatum	Chamise	Rosaceae	ADFA
Arctostaphylos spp.	Manzanita spp.	Ericaeae	ARCTspp.
Artemisia californica	California sagebrush	Asteraceae	ARCA
Baccharis salicifolia	Mule-fat	Asteraceae	BASA
Brassica nigra	Black mustard	Brassicaceae	BRNI
Ceanothus crassifolius	Hoary leaf ceanothus	Rhamnaceae	CECR
Ceanothus megacarpus	Bigpod ceanothus	Rhamnaceae	CEMEG
Ceanothus oliganthus	Hairy ceanothus	Rhamnaceae	CEOL
Cercocarpus betuloides	Mountain mahogany	Rosaceae	CEBE
Dendromecon rigida	Bush poppy	Papaveraceae	DERI
Eriodictyon crassifolium	Thickleaf yerba santa	Hydrophyllaceae	ERCA
Eriogonum fasciculatum	California buckwheat	Polygonaceae	ERFA
Helianthemum scoparium	Common rush-rose	Cistaceae	HESC
Helianthus cf. gracilentus	Slender sunflower	Asteraceae	HELIA
Heteromeles arbutifolia	Toyon	Rosaceae	HEAR
Lepechinia cardiophylla	Heart-leaved pitcher sage	Lamiaceae	LECA
Linanthus spp	Linanthus spp.	Polemoniaceae	LINspp.
Lotus scoparius	Deer weed	Fabaceae	LOSC
Malacothamnus fasciculatus	Chaparral bush mallow	Malvaceae	MALFAS
Malosma laurina	Laurel sumac	Anacardiaceae	MALA
Marah macrocarpus	Wild cucumber	Cucurbitaceae	MARMAC
Mentzelia spp.	Stick-leaf spp.	Loasaceae	MENspp.
Mimulus aurantiacus	Bush monkey flower	Scrophulariaceae	MIAU
Nassella pulchra	Purple needlegrass	Poaceae	NAPU
Nolina cismontana	Chaparral nolina (beargrass)	Agavaceae	NOCI
Quercus berbetifolia	Scrub oak	Fagaceae	QUBE
Rhus integrifolia	Lemonadeberry	Anacardiaceae	RHIN
Rhus ovata	Sugarbush	Anacardiaceae	RHOV
Romneya coulteri	Coulter's matilija poppy	Papaveraceae	ROCO
Salvia mellifera	Black sage	Lamiaceae	SAME
Solanum xanti	Purple nightshade	Solanaceae	SOXI
Trichostema lanatum	Woolly blue curls	Lamiaceae	TRLA
Yucca spp.	Yucca spp.	Agavaceae	YUCCA

Figure 2-6. Areas with contrasting densities of Tecate cypress skeletons. On the left is Stratum 1, where we detected a high density of seedlings and a low density of large skeletons. On the right is Stratum 11 where we had very high densities of small skeletons and comparable seedling densities

Areas with Live Cone Bearing Trees

In general, refugia are scattered throughout the original distribution and comprise small areas on smooth slopes not associated with ravines (refugia in Strata 5, 6, 8 and 9), larger areas along ravines (refugia in Strata 10 and 12, and refugia W-15; Figure 2-8), and scattered individuals on steep slopes in upper Coal and Gypsum Canyons (HW51). Figure 2-9 illustrates the location of all refugia and their densities. Some of these areas were previously reported by Harmswoth Associates (2007) and were not re-visited during the current surveys. The largest area with a high density of live adult individuals is located close to the bottom of Gypsum Canyon (area W15 in Figures 2-8 and 2-9). This area did not burn in the last two fires even though both fires burned the surrounding areas. The largest area with scattered individuals is located in the upper southwest section of Gypsum Canyon, and is dominated by outcrops and very steep slopes (HW5 in Figure 2-9). In this area we detected several trees along a ravine and its eastern slope (W13) that eventually connects with the largest refugium in Gypsum Canyon (W15). This refugium in the western portion of the distribution supports the largest trees recorded, with average heights of more than 6.5 m (Table 2-5 and Figure 2-10). In the Coal Canyon Ecological Reserve land, refugia are typically restricted to areas along ravines (6DA5, Figure 2-9). The biggest trees in this section are found in ravines with an average height of up to 6 m, but typically around 4 m (Table 2-5 and Figure 2-10). All other refugia correspond to small patches of less than 50 individuals scattered along smooth slopes at high elevations (Figure 2-11). In these areas average height is between 2.5-3 m. In fact, several of these areas have juveniles and seedlings intermixed with small adults.

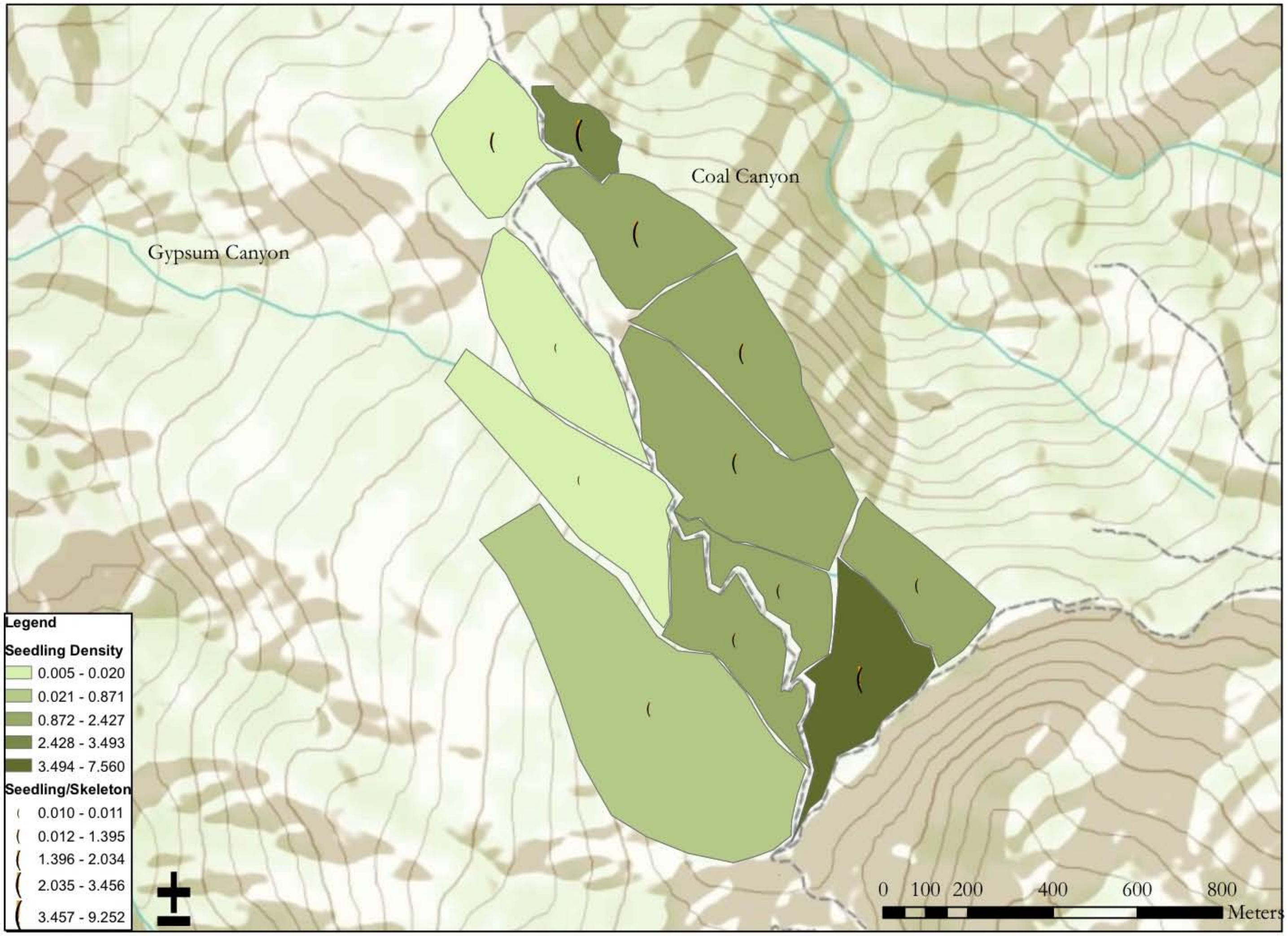

Figure 2-7a. Estimated Tecate cypress seedling density per strata (indiv/m^2) in the northern Santa Ana Mountains. Colors indicate different seedlings density and symbol size indicates different seedling per skeleton ratios. North/south directions are indicated by ±; north corresponds to the top of the cross. The study area is located in the USGS Black Star Canyon 7.5 minute quadrangle.

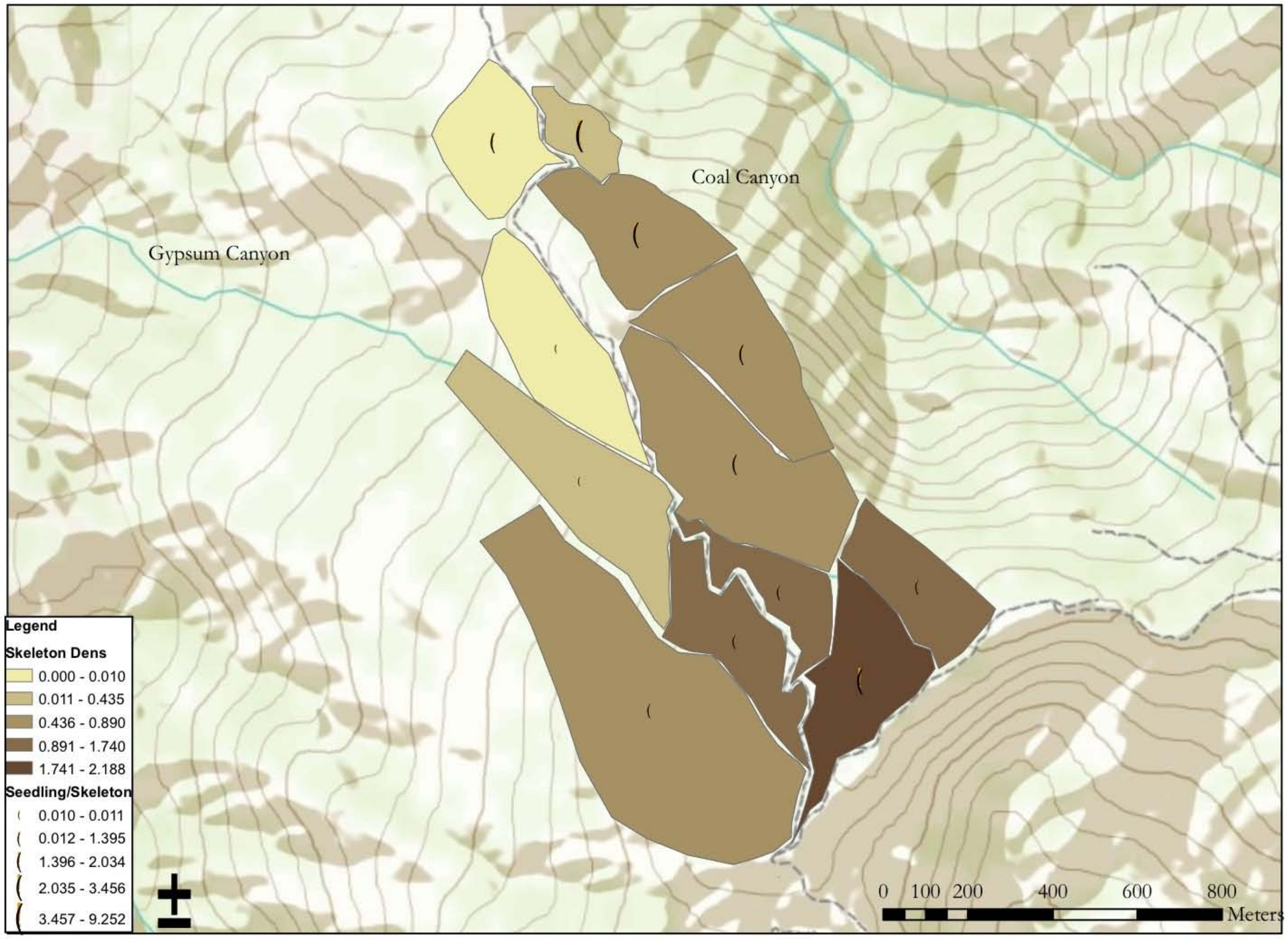

Figure 2-7b. Estimated Tecate cypress adult density per strata (indiv/m^2) in the northern Santa Ana Mountains. Colors indicate different adult density and symbol size indicates different seedling per skeleton ratios. North/south directions are indicated by ±; north corresponds to the top of the cross. The study area is located in the USGS Black Star Canyon 7.5 minute quadrangle.

Figure 2-8. Tecate cypress refugium in the northern Santa Ana Mountains. The area is on Irvine Ranch land with at least 2,000 individuals growing along a ravine (W 15 in Figure 2-9).

Despite this pattern of adult densities, areas with the highest average count of cones per tree are located on both smooth slopes and ravines. In fact, trees in W15 at the lower Gypsum canyon showed lower cone counts than many of the refugia detected in the Coal Canyon Ecological Reserve (Table 2-5) and may be due to density dependent effects (Dunn 1986). The area with highest cone count is located in Stratum 1 and corresponds to a few individuals with extremely high cone production. Unfortunately, several of these refugia are at lower elevations, along the border of the original Tecate cypress distribution. Given that seed dispersal is mostly by wind and water flowing downslope, the location of these current refugia imposes a conservation challenge; these seeds will probably disperse into unsuitable areas.

Recent Changes in Population Extent Due to Fire

The Santa Ana Mountain Tecate cypress population has experienced several large-scale fires since 1914. Table 2-2 summarizes the fires that consumed all or portions of the population between 1914 and 2009 and Figure 2-12 illustrates areas with different fire histories. The entire area burned twice between 1948 and 1967. After these two fires, Pequegnat (1955) and Armstrong (1978) reported profuse recruitment. There are no detailed maps of the extent of this population previous to 1982 or of the post-fire population extent. Armstrong estimated the total area with Tecate cypress at about 400 ha (Armstrong 1966), which coincides with the area reported by Spenger in 1985 (Spenger 1985). Nevertheless, we did not find any previous report with an assessment of changes in adult tree densities.

Harmsworth's report (Harmsworth Associates 2007) and our surveys indicate that prior to the 2002 and 2006 fires, areas with high Tecate cypress densities were restricted to milder slopes on the upper portion of both canyons, while scattered individuals grew on the steeper slopes or in outcrops. The eastern most portion of this population occurred just below Sierra peak in upper Coal Canyon (CNF4 in Table 2-5). This patch consisted of 20 large individuals that burned in 2002, showed some

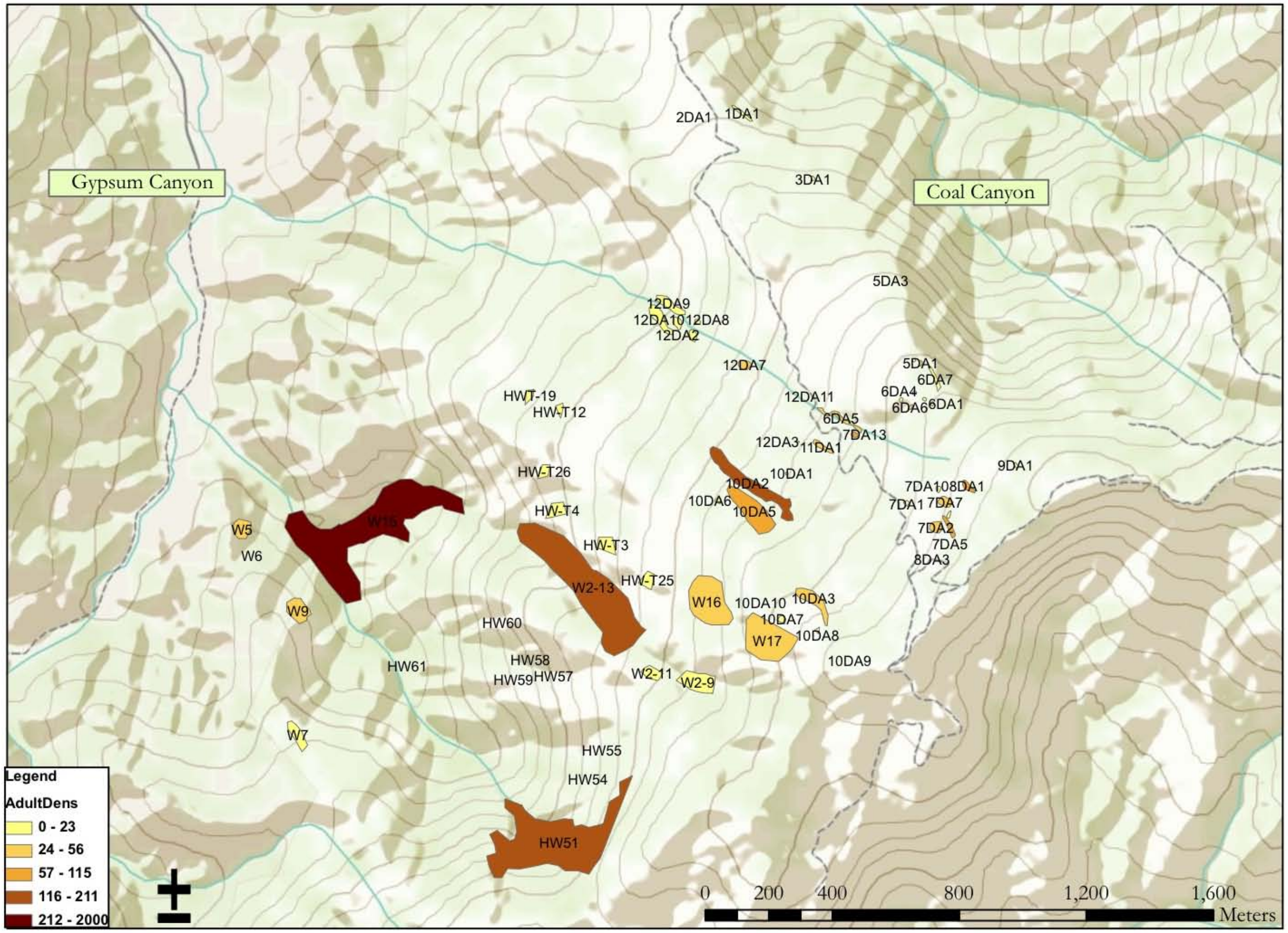

Figure 2-9. Refugia with live Tecate cypress adults in the northern Santa Ana Mountains following the 2002 and 2006 fires. Colors illustrate density (indiv/m^2) of Tecate cypress adults. Some of these areas were previously reported by Harmswoth Associates (2007) and were not re-visited during the 2009 census. These areas are indicated with the prefix HW. All other areas on Irvine Ranch Lands were named using a prefix W. The first two digits in the name of refuga in Coal Canyon Ecological Reserve correspond to the number assigned to the strata. North/south directions are indicated by ±; north corresponds to the top of the cross. The study area is located in the USGS Black Star Canyon 7.5 minute quadrangle.

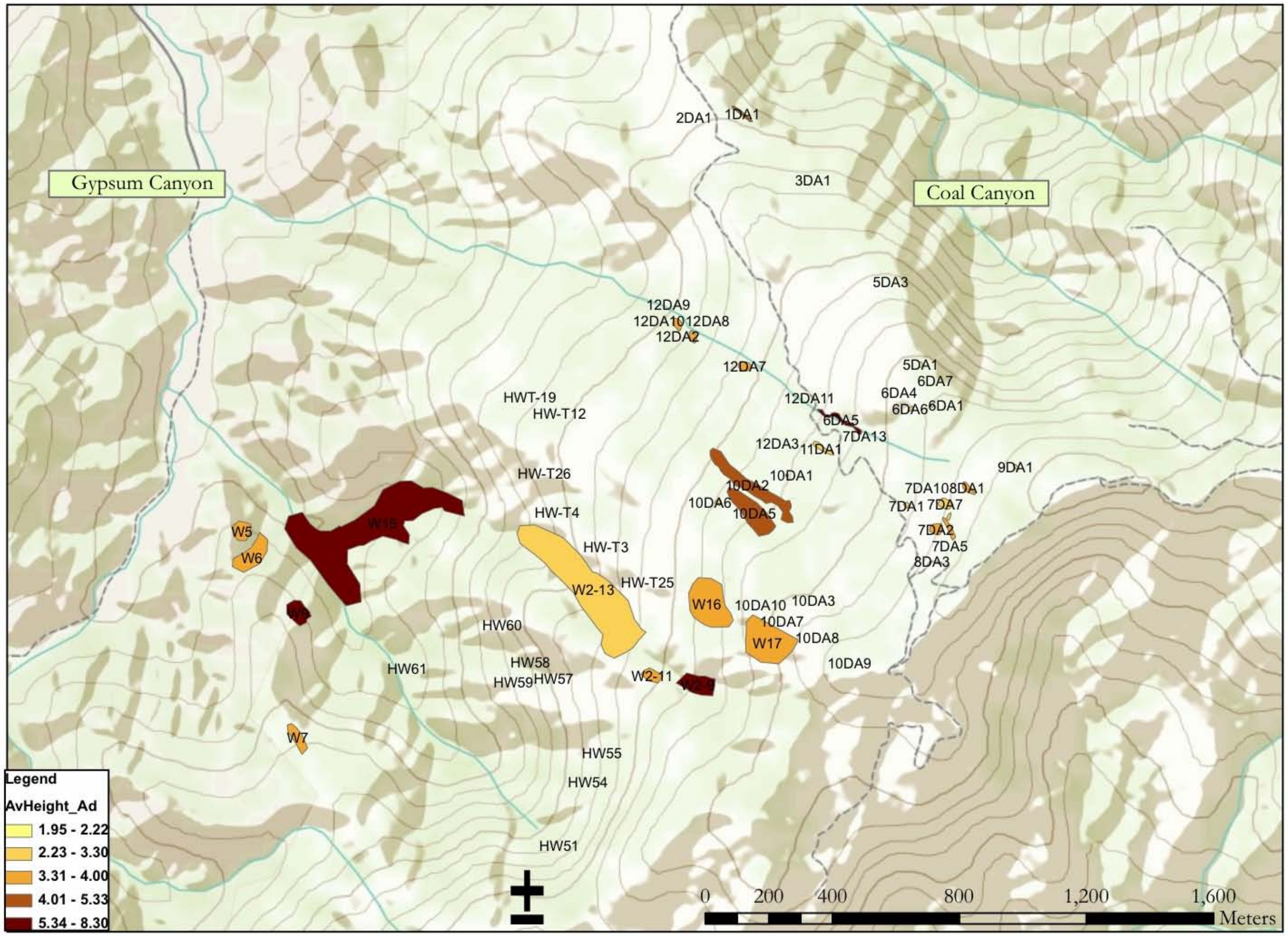

Figure 2-10. Height of live adult Tecate cypress in the northern Santa Ana Mountains following the 2002 and 2006 fires. Colors illustrate the average height of Tecate cypress adults. Some of these areas were previously reported by Harmswoth Associates (2007) but were not re-visited during the 2009 census (areas are indicated with the prefix HW). All other areas on the Irvine Ranch Land and the Coal Canyon Ecological Reserve were visited. A subsample of at least 5 trees were selected for measurements. Average height for small refugia are summarized in Table 2-5. North/south directions are indicated by ±; north corresponds to the top of the cross. The study area is located in the USGS Black Star Canyon 7.5 minute quadrangle.

Figure 2-11. Refugia with cone-bearing adults that survived the recent fires in the Coal Canyon Ecological Reserve. The picture on the left is from Stratum 8 showing several small refugia in an area that was previously dense Tecate forest (Refugium 8DA). The picture on the right shows a larger refugium running along a ravine at lower elevations on Stratum 12 (Refugium 12DA9).

recruitment in 2005 (DeGouvain and Anzary, 2006), but subsequently burned again in 2006. We did not detect any recruitment in this location in 2009. Recently, a satellite population along the western slopes of Fremont Canyon was included into the original extent reported in 1948 by Wolf (Harmswoth Associates, 2007). This patch had about 70 adults and burned in 2006; we detected a few seedlings this year (Table 2-5). During the 2002 Green fire most of the area with Tecate cypress burned, except for a large portion of Irvine Ranch Land located on the ridge between Fremont and Gypsum Canyons (Harmsworth Associates, 2007). On the east side of the population within Coal Canyon Ecological Reserve, a large area west of the ridge between Gypsum and Coal Canyons did not burn, as well as several large areas along ravines at the bottom of Gypsum Canyon and the satellite population in Fremont Canyon. In their 2003 census, Harmsworth Associates reported seedlings growing sparsely in the remaining patches throughout the burned area (Harmswoth Associates 2007).

In 2006 the Sierra Peak fire burned over most of the western portion of the main stand, on Irvine Ranch Land and the eastern edge of the Coal Canyon Ecological Reserve and the Cleveland National Forest. Interestingly, the footprint of this fire barely overlapped with areas burned in 2002. The Sierra Peak fire burned over large areas in upper Gypsum canyon that escaped the 2002 Green fire. The satellite population in Fremont Canyon also burned during this fire. Harmswoth Associates (2007) reported very low recruitment after this fire, and described the remaining population as a collection of small areas restricted to ravines with very few adult trees (Figure 2-13). They estimated that after the 2006 fire the Santa Ana population of Tecate cypress was reduced to approximately 2,000 mature trees distributed among several small areas scattered through the original population's extent.

Despite the fact that footprints of the two most recent fires barely overlapped, recovery has been particularly low in some areas, especially on the west side of upper Gypsum Canyon. The estimated age of Tecate cypress adults in this area before the 2006 fire is about 24 years, since this area last burned in 1982. With this age, recruitment after fire should have been possible given that individuals at this age are producing large quantities of cones (Dunn 1986). A possible explanation for the observed pattern is the fact that the two growing seasons after the fire were particularly dry; with precipitation reaching a record low in 2007. Drought could have prevented seed germination and successful establishment even when seed limitation was not a factor. In addition, drought stress likely affected new recruits after the 2002 February fire, as spring 2002 was also an extreme drought year.

Spatial Variation in Pre-fire and Post-fire Stand Structure

Changes in pre-fire structure explain differences among strata in post-fire seedling density. Figures 2-14 to 2-16 depict the structure of the different strata prior to the last fire in 2002 (gray bars) and the proportion of seedlings and live adults after the fire (blue bars). Size classes combine information on height and diameter (Table 2-3). Proportions were separately calculated in reference to pre- and post-fire total counts. Figures 2-14 to 2-16 illustrate how different pre-fire population structure translates into comparable post-fire recruitment densities, which suggests a strong spatial variability in reproductive potential and habitat suitability. Strata could be grouped into three distinct categories according to the pre- and post-fire population structure combination. Strata 1 and 3 that have a low density of skeletons, but most of them are large and with profuse cone production (Figure 2-11, left). These areas were last burned in 1967, which means that by the 2002 fire adults were at least 35 years old. In both areas we recorded medium to large seedlings; in fact seedlings in these areas were the largest (Figure 2-14).

Areas with medium to high densities of skeletons that tend to be smaller in size constitute a second group. Strata 6-9 and 11 fall within this category with high densities of short and slender skeletons (Figure 2-9, right) that fall into size classes 3 and 4 (Figures 2-14 and 2-15). Prior to the 2002 fire, these areas last burned in 1967. In this case, many small adults with low per capita cone production guaranteed seed availability after the fire. With the exception of Stratum 11, these strata have post-fire structures with higher proportions of larger immature trees (Class 2) at most seven years of age; this pattern was accentuated by Stratum 7 where most of the immature trees were size class 2. Stratum 11 had a higher density of smaller juveniles (Class 1), and smaller pre-fire adults (Class 3). This latter stratum had one of the lowest percentages of bare ground due to a denser layer of native shrubs. A denser community with larger shrubs might have imposed growth limitations that translated into seedling size differences among strata with the same fire histories (Strata 6-9 in Table 2-5). Stratum 10 represents a category in itself. In this area, pre-fire structure was dominated by medium to big trees at intermediate densities with low recovery post-fire. New recruits in this area tended to be relatively small despite the low vegetation cover (Table 2-5). Stratum 12 constitutes another category characterized by low density of skeletons where recovery is minimal. Although we did not specifically explore size classes of skeletons in Strata 2 and 4, the pattern we observed in Stratum 12 may apply to these two areas. These last two categories correspond to areas that burned in 1967 and 1982, which implies that most adults that burned in 2002 were at least 20 years old. Low recovery in these last two categories is probably due to the low pre-fire density of younger adults.

In addition to the structure of the strata in Coal Canyon Ecological Reserve, we also explored the pre-fire structures of the satellite population at Fremont Canyon (F1 in Figure 2-2), and of the largest refugium at the bottom of Gypsum Canyon (W15). The patch at Fremont Canyon shows

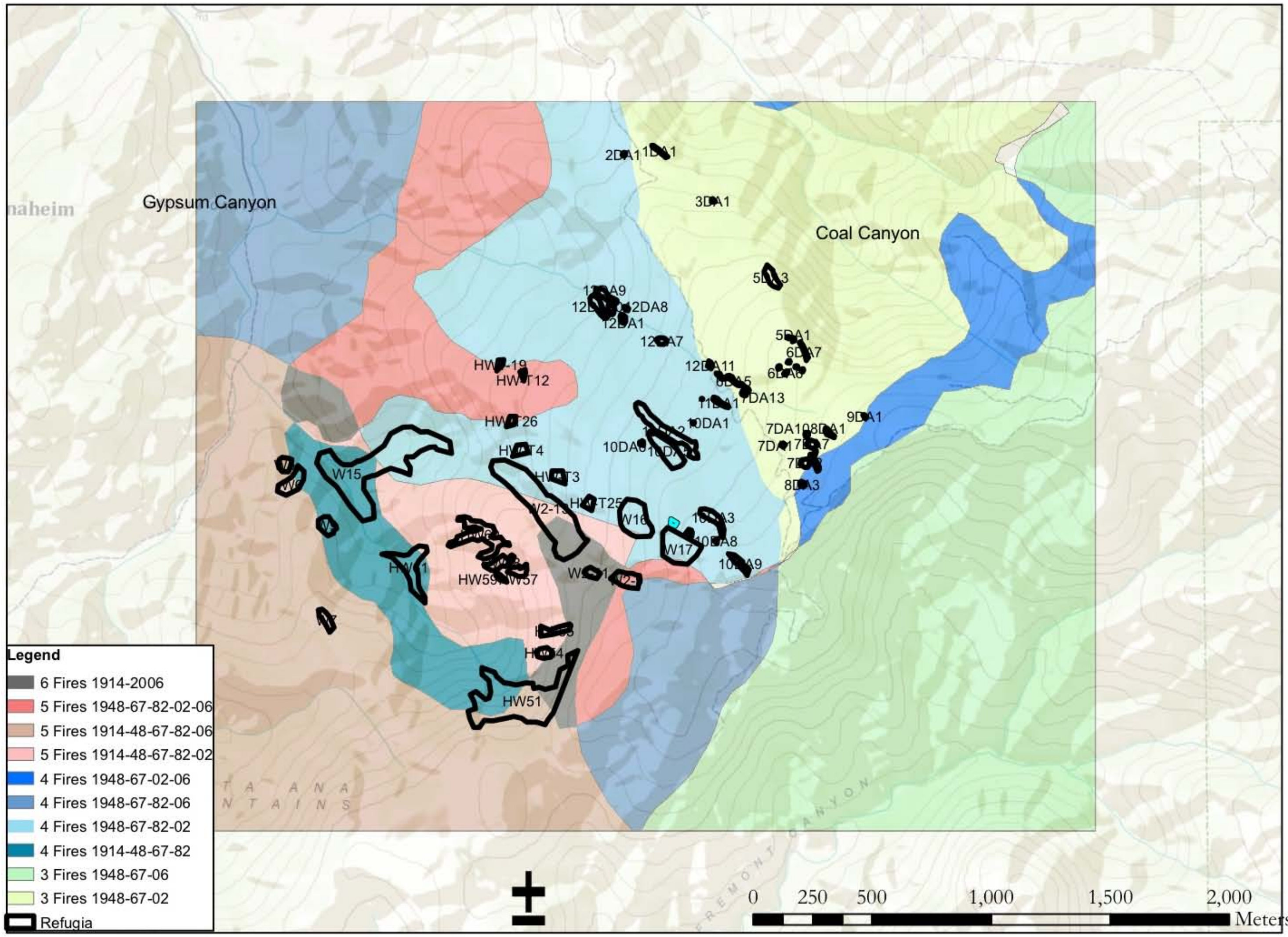

Figure 2-12. Frequency of fires throughout the main stands of Tecate cypress in the northern Santa Ana Mountains. We included the seven largest fires that have burned over parts of the main Tecate cypress stand in the last 95 years (1914-2009). North/south directions are indicated by ±; north corresponds to the top of the cross. The study area is located in the USGS Black Star Canyon 7.5 minute quadrangle.

Figure 2-13. Burned stand of Tecate cypress on Irvine Ranch land in the northern Santa Ana Mountains. The bottom of the picture shows a burned area with a formerly high density of Tecate cypress. The upper portion of the picture shows steep slopes where some Tecate trees escaped 2002 and 2006 fires and persist in refugia.

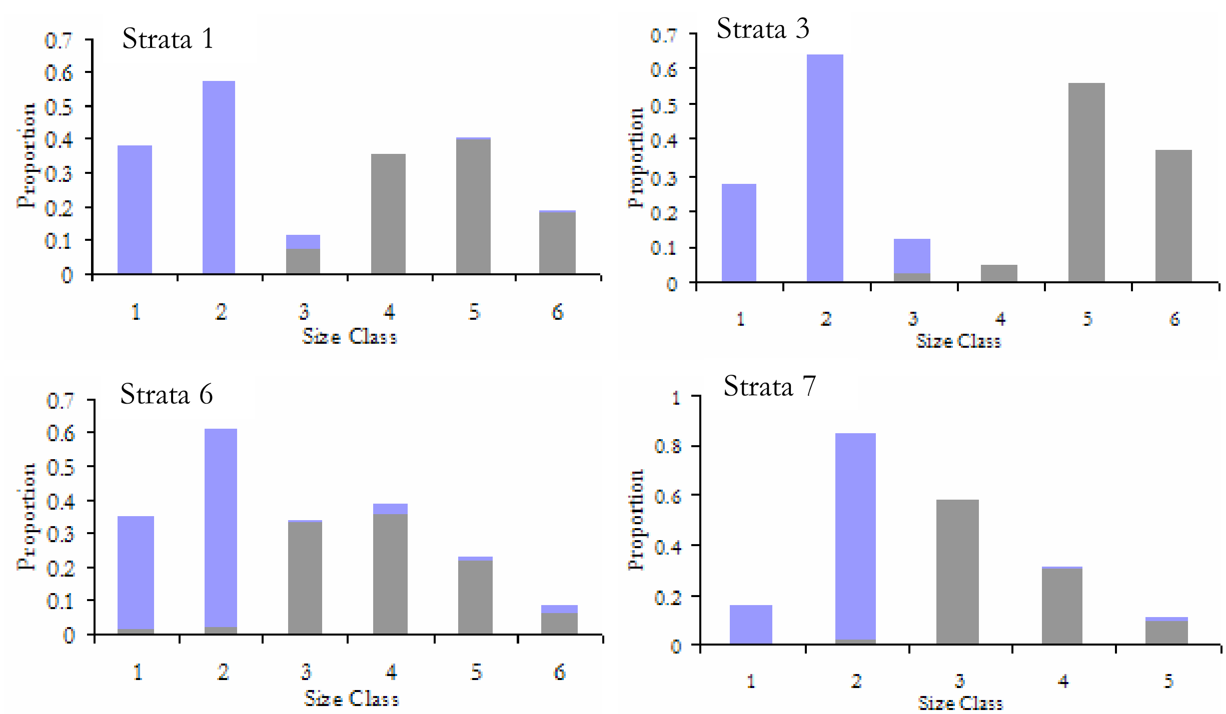

Figure 2-14. Pre- and post-fire structure of northern Santa Ana Mountains Tecate cypress populations in Strata 1, 3, 6, and 7. Gray bars represent structure of skeletons and blue bars represent individuals that grew since the last fires or survived the fire.

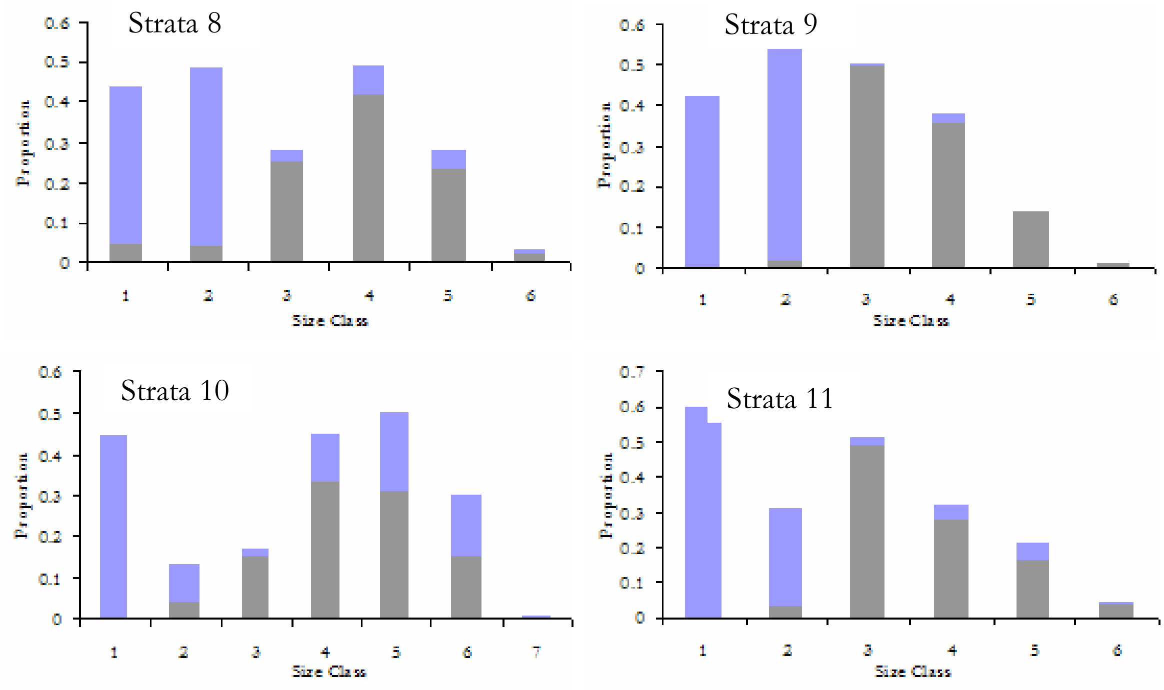

Figure 2-15. Pre- and post-fire structure of northern Santa Ana Mountains Tecate cypress populations in Strata 8 thru 11. Gray bars represent structure of skeletons and blue bars represent individuals that grew since the last fires or survived the fire.

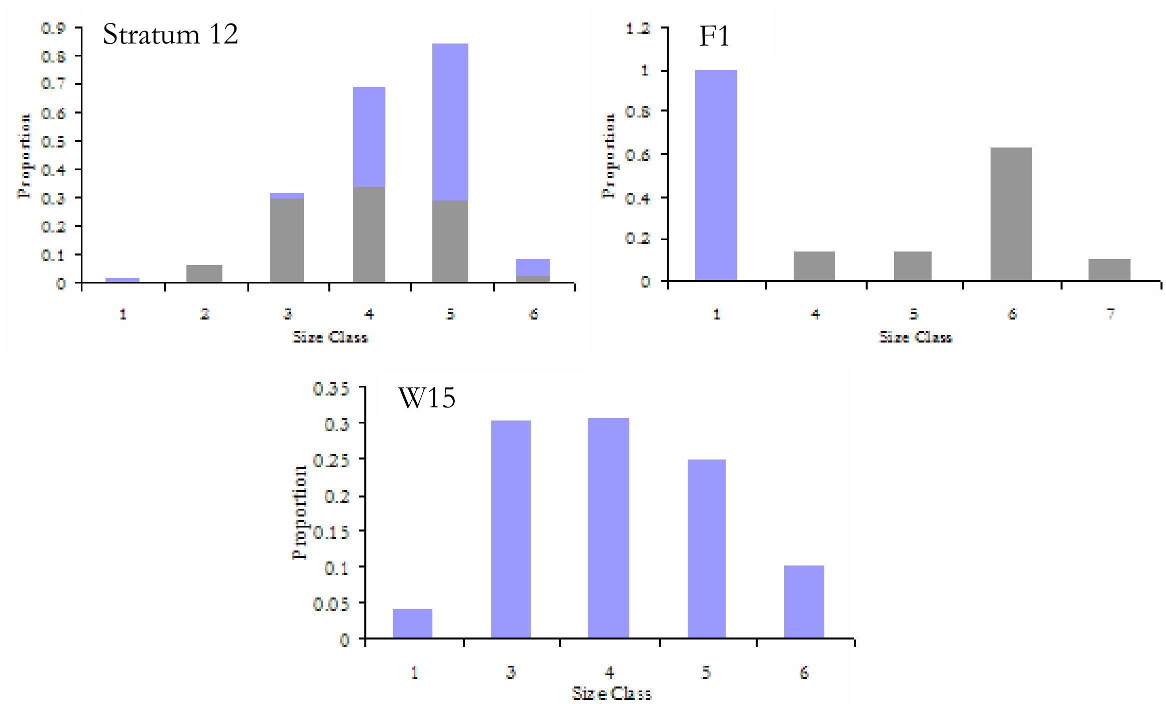

Figure 2-16. Pre- and post-fire structure of Tecate cypress populations in Strata 12, Fremont Canyon (F1), and Refugium on Irvine Ranch land (W15). Gray bars represent structure of skeletons and blue bars represent individuals that grew since the last fires or survived the fire. In the refugium, there were no post-fire individuals, as this stand did not burn.

similar pre-fire structure to Strata 1 and 3 in Coal Canyon; nevertheless, recruitment was much lower in this area, and seedlings are smaller. This area burned in 2006, which implies that seedlings were at most three years old. On the other hand, the largest refugium (W15) shows a structure composed mainly of medium size trees with very few immatures and very low cone production. Despite the fact surrounding areas burned in 2002 and 2006, this area probably last burned in 1982. Trees in this area are about 27 years old. Some areas closer to the ravine have large Tecate cypress intermixed with large riparian trees, suggesting patches with much older Tecate cypress trees (Figure 2-17).

Discussion and Recommendations

The main objective of this section was to provide an updated description of the Santa Ana Mountains population of Tecate cypress. We conducted an intensive survey of the area where this species has been reported in order to define the current extent of the population and estimate its density and structure. This survey was conducted between March and June 2009 and encompassed the entire area at the northern extreme of the Santa Ana Mountains where this species has been reported.

Our results indicate effective population size of the Santa Ana stand has been significantly reduced in the last 20 years, although we found little evidence that the extent of the population changed. Initial descriptions of this species indicated that the population at the Santa Ana Mountains covered an area of approximately 400 ha along the ridges between Gypsum, Coal, and Fremont Canyons. More accurate descriptions suggest that the actual extent of the original population was about 200 ha with additional disconnected patches growing in Fremont Canyon and along the main divide in the Cleveland National Forest. Despite the discrepancies in areal estimates, the territory described as occupied by Tecate cypress essentially remained unchanged until 2000. Nevertheless, the most recent fire events in 2002 and 2006 have produced a strongly fragmented population with a much smaller effective population size (approximately 3,800 adults) and recruitment area (approximately 60 ha). The primary reason for this reduction may be related not only to an increase in fire frequency over the last 40 years, but also to the effect of extreme environmental conditions (drought) and variation in pre-fire densities across the area.

This population has experienced six major fires in the last 95 years (Table 2-2 and Figure 2-12). Two of these fires in 1948 and 1967 burned the entire population, while the remaining fires burned between 20 and 90% of the original Tecate cypress population. Despite the extent of these past fires, post-fire assessments reported profuse recruitment (Armstrong 1966 and 1978). By 1967, most of the population was at least 19 years of age. Although this is below the age of peak reproduction for Tecate cypress (Dunn 1986), subsequent reports and maps of adult locations indicate full population recovery in the original area. More recent fires in 1982, 2002 and 2006 created a mosaic of areas with different fire histories that strongly influences population density and structure (Figure 2-12). We found that the location and timing of recent fires produced a strongly fragmented population with a smaller effective population size. This fragmentation is not only in terms of increasing isolation of patches with cone-bearing adults, but it is also in terms of a discontinuity between reproduction and recruitment. The western extreme of the population located on Irvine Ranch land burned almost entirely during each of the recent fire events. This area is currently characterized by an extremely low juvenile density and at least two disjunct areas with unburned adults in upper Gypsum Canyon and at the bottom. In contrast, the eastern portion of the population has only experienced the 1982 and 2002 fires and supports higher densities of immature trees and lower numbers of reproductive

Figure 2-17. Tecate cypress in riparian forest at the bottom of Gypsum Canyon.

adults. In both areas, refugia that hold reproductively active adults are located at the edges of the distribution, from where dispersal to higher elevation areas is improbable. In this sense, conservation strategies should devote efforts to tackle this difficulty by improving seed supplies in higher elevation areas suitable for recruitment, but which lack adult seed input.

Our survey also indicates the strong influence that fire history and site-specific habitat characteristics have on population recovery. The eastern portion of the population is divided into two distinctive areas, one that burned in 1982 and again in 2002 and the other that remained unburned between 1967 and 2002. The area that burned in 1982 currently shows very low juvenile densities, while recruitment is profuse in the other area. Given that previous studies report good recovery of the 19 year old Santa Ana Mountain stand after the 1967 fire (Armstrong, 1970), our results suggest that pre-fire densities and specific habitat characteristics play a major role in defining potential recovery after fire. Comparisons of strata that burned in 1967 and 2002 indicate that habitat characteristics strongly control recovery potential. Before the fire of 2002, areas at lower elevations had a few large adults with great reproductive capacity, while at higher elevations, the population was characterized by dense patches of small adults with lower reproductive capacity. Despite these differences, we detected comparable recruitment in these two areas. This suggests that higher pre-fire densities might not be required to guarantee post-fire population recovery if growth conditions are good. Future assessment of potential post-fire population recovery for this species should incorporate spatially specific information about habitat suitability for recruitment in addition to the age of the pre-fire population. A possible restoration strategy with the threat of large fires will be to enhance recruitment in some of these areas that can support a few reproductively successful individuals.

Figure 2-18. Refugium with a large proportion of dead but unburned Tecate cypress adults. This area corresponds to refugium 10DA5.

In addition to frequent large fires, environmental conditions also impose an imminent threat to the persistence of Tecate cypress in the Santa Ana Mountains. During the 2009 surveys we did not detect significant recruitment after the 2006 fire, despite a high pre-fire adult density in some areas (e.g., western extreme of the distribution on Irvine Ranch Land). This is likely due to the extreme dry conditions that dominated the growing seasons following the 2006 fire. In addition, we detected several locations with a high proportion of dead tress that did not burn in the last fire (Figure 2-18). The affected areas were mostly large refugia that are close to ravines in both the east (10DA5) and west (slopes of W15) sides of the original distribution. The fact that we still detected high recruitment is some areas despite these extreme environmental events highlights the importance of asynchrony between fire events and droughts. It also suggests that there is a threshold for immature Tecate cypress after which seedlings acquire resilience to sporadic hydric stress conditions. Conservation and restoration efforts should account for small-scale variability in growing conditions when identifying suitable areas for Tecate cypress plantings.

In summary, results from our surveys made evident three characteristics of the Santa Ana population that have important implications for conservation and restoration efforts:

- The current population is highly fragmented not only because cone-bearing individuals grow in small and isolated patches, but also because most of these refugia are located in areas where probability of successful recruitment is low (i.e., low elevation edges of the distribution). Thus, a management challenge is to enhance seed supply in higher elevation areas were recruitment is possible.

- Current recruitment patterns reflect the effects of fire history, habitat characteristics and pre-fire structure on post-fire recovery. Thus, resources should be devoted to identify areas with optimum growing conditions where a few highly productive adults guarantee seed supply following fire. With predictions of increased drought frequency and severity resulting from a changing climate, it may be essential for post-fire recruitment to find areas for restoration that are relatively resistant to the effects of drought.

- Frequent large fires put the entire population at risk, particularly when the majority of the current population will not reach maximum seed production for many years. While there are natural refugia within the current distribution, these are not enough to ensure adequate recovery following a large fire, particularly if it occurs in the near future. If fire frequency remains high, a more widely distributed population structure may be necessary to ensure that a greater proportion of individuals can escape each fire and grow to reproductive maturity.

3.0 FIRE RISK ASSESSMENT AND POPULATION DYNAMICS

Tecate cypress has several life history traits that make it especially vulnerable to changes in fire regime. Tecate cypress is a fire dependent, obligate seeder that establishes after a fire (Vogl et al. 1977; Zedler 1981; Dunn 1986). In this species, like any other with serotinous cones, most seeds are released following a fire as the cones require long periods of time to dry out and open (Armstrong, 1966), and intense heat during fire speeds up this process. After a fire, germination and recruitment are profuse, which has also been suggested as evidence of the fire dependent nature of this species (Armstron, 1966; Dunn, 1986); although there is little information about recruitment between fire events. Dunn (1986) estimated that age specific survival of Tecate cypress increases with age; corresponding to a type III survival curve. Markovchick-Nicholls (2007) suggested that this species experiences an intense density dependent mortality based upon data provided by Paul Zedler. Although this dataset is not detailed enough to support the specific function she used, her equation is the best approximation we have to describe this process. Several studies have found that Tecate cypress can start reproducing at relative early ages (as soon as 6-7 years of age; Zedler 1977 and 1984), but peak cone production is only reached when trees are between 35 and 40 years old (Dunn 1986). There is little information about changes in cone production after this age, although some authors assume a post-reproductive stage (De Gouvenain and Ansary 2006). Seeds may remain viable in closed cones for many years (Spenger 1985), although there is no explicit evidence of this pattern or any explicit investigation of seed viability. Dispersal is considered minimal for this species and assumed to be mostly downhill and facilitated by wind and water currents (Armstrong 1966 and Zedler 1986). These life history characteristics make Tecate cypress particularly vulnerable to the current trend of increasing fire frequencies in Southern California. Populations are at risk of local extinction whenever fires are so frequent that new recruits are unable to reach maturity and contribute to the seedbank or whenever fires are so infrequent that most seeds are not released and dispersed. In these cases, recruitment is lower than levels that allow for population self replacement.

The objective of this study is to investigate the susceptibility of the Santa Ana Mountains Tecate cypress population to different fire regimens. For this purpose, we conducted a preliminary evaluation of fire susceptibility throughout the study area using a fire behavior modeling approach. We incorporated these results into a population model calibrated with data from our 2009 census. This information will complement previous fire modeling studies conducted on Irvine Ranch Land, at the northern most extreme of the Santa Ana Mountains (Anderson 2009) and previous demographic studies on Tecate cypress (Dunn 1986; De Gouvenain and Ansary 2006; Markovchick-Nicholls 2007).

Background

The current distribution of Tecate cypress in the Santa Ana Mountains is restricted to an area of approximately 235 ha in Gypsum and Coal Canyons. Although the historic distribution was relatively uniform throughout this area, frequent fires in the last 27 years have significantly reduced adult densities and areas of active recruitment. During a survey conducted between March and April 2009, we identified 75 patches with adult individuals; the total area with living adults was 35 ha. We also identified areas of active recruitment encompassing approximately 87 ha. Areas supporting cone-bearing adults are small and sparsely distributed throughout the landscape, while areas of active recruitment are concentrated in upper Coal Canyon. Thus, the current distribution of Tecate cypress is characterized by a strong segregation in the location of adult and seedling trees. Given that this species is locally restricted and exists in relatively small numbers of individuals per stand, state and local agencies in California have increased their level of concern for the conservation status of this species, especially in light of current changes in environmental conditions.

The Santa Ana population experienced several large-scale fires since 1914 (Table 2-2). The entire area burned twice; in 1948 and 1967. After these two fires, Armstrong (1978) reported profuse recruitment. Although there are no detailed maps of the extent of this population previous to 1982 and post-fire, Armstrong estimated the total area with Tecate cypress at about 400 ha (Armstrong, 1966), which coincides with the figure reported by Spenger in 1985 (Spenger, 1985).

Previous analyses of fire frequency in Southern California estimated fire return intervals in this area of between 30-40 years (Keeley 2000; Moritz et al 2003; Markovchick-Nicholls 2007). In a recent study, Anderson (2009) estimated that at the northern most extreme of the Santa Ana Mountains, the Irvine Ranch lands have faster fire return intervals than areas further south along Highway 241. Areas with the highest likelihood of burning during their simulations are located along Santiago Canyon. Although Anderson worked at a scale of resolution much lower than the scale used in this study, his results are evidence for the higher fire susceptibility of areas where Tecate cypress are currently located.

Dunn (1986), De Gouvaine and Ansary (2006), and Markovchick-Nichols (2007) explored the relationship between fire return intervals and long-term population growth for this species. Dunn suggested that the optimal fire return interval for this species is between 35-40 years; his estimations were based on the predicted relationships of age and cone production and age and survivorship. De Gouvaine and Ansary (2006) found a positive relationship between fire return interval and population growth rate, and suggest that fire return intervals shorter than 40 yeas would correspond with negative population growth. Finally, Markovchick-Nichols (2007) explored different management scenarios for a hypothetical Tecate population. She concluded that Tecate cypress populations are not only sensitive to fire return intervals but also to variability of fire regime; in fact she found that Tecate populations require a mean return interval of 44+ years, and that this interval needs to be relatively consistent to be stable. Similarly, she estimated that Tecate cypress populations would be more susceptible to success or failure of fire management scenarios than to seed collection strategies.

Methods

Fire Risk Assessment

We estimated the fire risk in areas where Tecate cypress is currently present using the fire behavior simulation program Flammap (Fire Sciences Library 2004). This program allows us to have a quick spatially explicit estimation of burn probabilities under constant environmental and fuel conditions. Under constant conditions, the output generated with Flammap primarily reflects the effect of topographic variables (elevation, slope and aspect). In order to assess the fire risk at normal and extreme environmental conditions, we simulated fires throughout the entire study area using environmental conditions that were previously categorized by their probability of occurrence. Thus, we ran separate simulations under normal, rare, severe, and extreme environmental conditions. This involved two steps. First we combined climatic and fire history information to categorize environmental conditions according to their susceptibility to promote extreme fires. We then incorporated the climatic conditions associated with each category into Flammap simulations.

We assessed burn probabilities in an area that covers the main stand of Tecate cypress, at the northernmost end of the Santa Ana Mountains (Figure 2-4). In order to characterize the climatic conditions in the study area, we used historical weather reports from four different Remote Automated Weather Stations (RAWS; Table 3-1). This information was combined with fire historical data from three different sources. We used historical fire records from the Cleveland National Forest that compile fire event reports from the U.S. Forest Service, records provided by Calfire and a dataset of all fires reported in Orange County and compiled by the Orange County Fire Authority (Table 3-2). We compiled records from these three agencies into a single dataset that was then imported into Fire Family Plus for further analyses.

Table 3-1. Remote Automated Weather Stations (RAWS) used to characterize historical climatic conditions in the Santa Ana Mountains population of Tecate Cypress. Data were obtained from the National Fire and Aviation Management Web Application site (FAMWEB).

Station Name (Station ID number)	Location	Coordinates	Elevation (m.a.s.l.)	Years of Data
Fremont Canyon (045736)	Fremont Canyon, Irvine Ranch, Santa Ana Mountains, Orange County	33° 48' 29" N, 117° 42' 40" W	542.8	1995-2004
Temescal Fire Station (045611)	Temescal, Sand Diego County	33° 45' 45" N, 117° 28' 58" W	342.9	1961-1970 1972-2008
Tonner Canyon (045453)	Los Angeles County	33° 56' 51" N, 117° 49' 20" W	408.4	2006-2008
Corona Fire Station (045618)	Corona, Riverside County			1985-2008

Table 3-2. Summary of fire occurrence reports used to characterize fire season throughout the Santa Ana Mountains population of Tecate cypress.

Agency	Area	Years of Data	Data Source
U.S. Forest Service	Cleveland National Forest	1970-2008	Famweb; Fire occurrence files
Calfire	Orange County	1995-2008	Calfire
Orange County Fire Authority	Orange County	1947-2007	Orange County Fire Authority

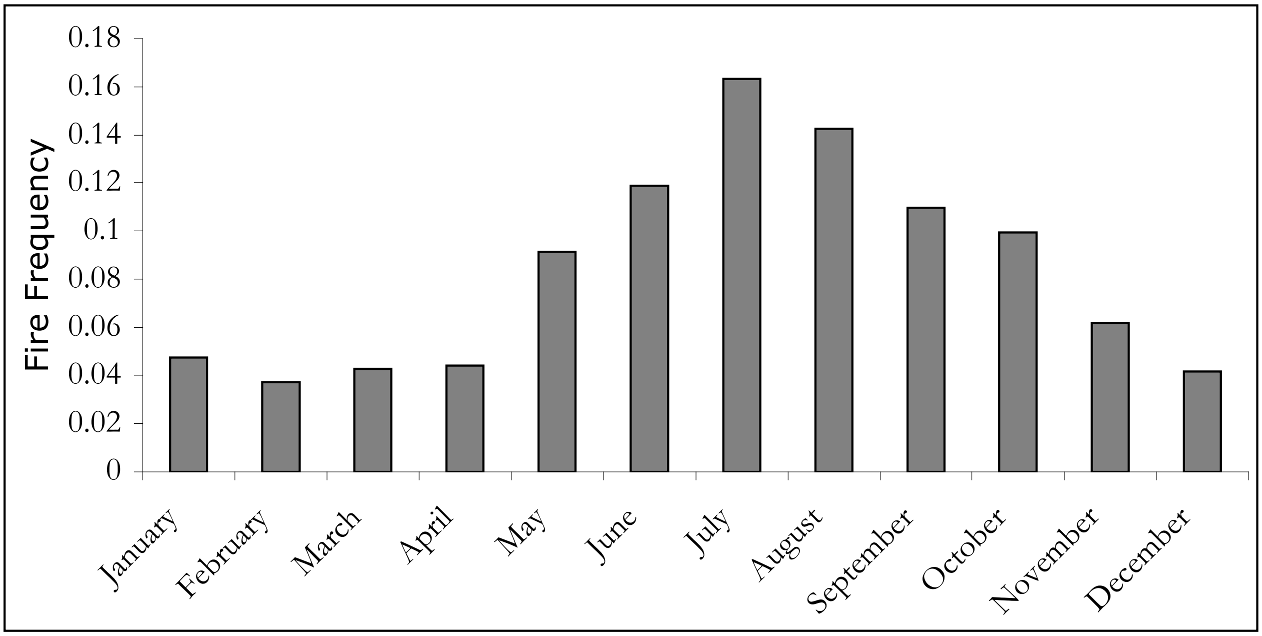

Figure 3-1. Fire frequency in southern California. Fire reports from U.S. Forest Service, Calfire, and the Orange County Fire Authority. This data set includes fire events from 1974 to 2008.

We used Fire Family Plus to define fire season and to describe weather conditions during the months of peak fire frequency. Fire frequency peaks in July with frequencies higher than 0.09 between May and October (Figure 3-1). This was considered the time span of the fire season. Fire occurrence data and historical weather information were associated in Fire Family Plus. In order to characterize the weather conditions during the fire season, we calculated the following parameters for each of the weather stations during the May-October season: spread component, temperature (maximum and minimum), relative humidity (average, maximum, and minimum), wind speed and direction, and fuel moisture (1-hour, 10-hour, 100-hour, herbaceous and woody). The spread component is a rating of the forward rate of spread at the head of a fire and is calculated using wind speed, slope, fuel bed and particles (Schlobonm 2002). One to 100 hour fuel moisture values refer to the percent moisture of dead organic fuels in different fuel size classes. These size classes relate to the time fuels take to lose a fixed percentage of their water content. For example, one hour fuel moisture represents the modeled fuel moisture content of dead vegetation of less than a quarter of an inch diameter that take about one hour to lose a certain percentage of moisture. Herbaceous and woody fuel moisture values refer to the modeled percent moisture of herbaceous and woody vegetation. These fuel moisture percentages are calculated by considering vegetation type, precipitation and relative humidity data. After generating season reports, data manipulation was minimal. We cleaned up weather reports by eliminating records with incomplete weather parameters.

For the spread component rate we created four percentile categories classified as normal, uncommon, rare, and extreme (Table 3-3) and that were characterized by weather conditions. We summarized the frequency of various weather conditions in the historical records for each percentile category. In addition to the percentile groups, we estimated the preponderant wind direction at each weather station for all stations (Table 3-4). These values were used as weights in the final calculations of burn probabilities.

Using the weather and fuel moisture information associated with each percentile group, we created the fuel moisture, wind and weather files needed to define initial fuel conditions before running Flammap simulations. Flammap uses different fire spread models, which incorporate several equations to estimate fire behavior for different vegetation complexes. In our simulations we used the standard Anderson's 13 fire spread model, which has been suggested to estimate fire behavior under severe environmental conditions well (Anderson 1982). The initial fuel moisture file specifies the live and dead fuel conditions that are incorporated into each of Anderson's 13 fuel models. With conditioning, Flammap adjusts dead fuel moistures based on aspect, elevation, and previous weather in a user-specified conditioning period. For all our runs, we used a conditioning period of five days.

We started the simulation process by constructing a landscape raster file that compiled raster layers for elevation, slope, aspect, Anderson's 13 model classes, and canopy cover. We obtained these raster layers from the Landfire web site, which provides 30 m resolution raster files for these parameters. These layers were transformed into a 10 m raster file and were combined with slope and aspect files derived from 10 m DEM files (www.landfire.org). We also incorporated into the landscape file information on stand height, canopy base height, and canopy. Raster layers corresponding with these parameters were also obtained from the Landfire web site.

We ran 64 simulations in Flammap using this landscape file to obtain burn probability maps for the entire study area. The burn probability maps generated with this procedure correspond to the number of times a cell burns after considering 1000 random ignition locations. In this sense, burn probabilities should be interpreted as an overall susceptibility to fire, rather than an accurate estimate of the actual burn probability. We did one run for every combination of weather percentile class (0-79, 80-89, 90-97, 98-100) and wind direction (N, NE, E, SE, S, SW, W, NW). In addition, we ran each combination at two conditioning times (4:00 in the morning, and 2:00 in the afternoon), which correspond to times of minimum and maximum temperatures. For each percentile class, burn probabilities were combined to produce a single weighted average. Weights for these calculations were derived from frequency of wind directions in the studied region (Table 3-4). During this calculation we assigned the same weight to burn probability maps generated using a morning end conditioning time (4:00 am) and an afternoon conditioning time (2:00 pm).

Finally, in order to estimate burn probabilities during extreme Santa Ana wind conditions we estimated the weighted average of burn frequencies using only burn probability maps generated with extreme weather conditions (percentile class 98-100) and winds blowing from the north and northeast. Santa Ana winds are hot and dry winds caused by pressure differences between southern California's shore and interior deserts (Westerling et al. 2004). Although these winds can reach gust speeds of 50 miles per hour, our long-term average estimated a maximum average velocity during Santa Ana conditions of 25 miles per hour.

Population Dynamics

We used a size-based population model with a stochastic environment to investigate the effects of different fire regimes and habitat heterogeneity on population persistence of Tecate cypress. Our approach explored population dynamics at two levels. First, we used results from our 2009 survey of the Santa Ana population to calibrate a baseline matrix model. In this model a matrix is used to compile the average individual probabilities of surviving and growing for different size classes. The matrix also incorporates information on size-specific reproduction. In addition to this population matrix, we used a dynamic environmental matrix to incorporate the effect of sporadic fire events.

Table 3-3. Weather conditions associated with each spread component percentile group. We created four percentile groups using the spread component value for all four weather stations between 1961 and 2008. The sSpread component summarizes the effect of topography, fuels and wind speed on the horizontal rate of fire spread. We used historical weather data to characterize each percentile group by weather conditions. Percentile group 0-79 was categorized as Normal, 80-89 as Uncommon, 90-98 as Rare, and 98-100 as Extreme.

Weather Station	Percentile Group	Average maximum Temperature (°F)	Average Minimum Temperature (°F)	Average Relative Humidity (%)	Average Maximum Relative Humidity (%)	Average Minimum Relative Humidity (%)	Average Wind Speed (miles/ hour)	Average of 1 hour fuel moisture (%)	Average of 10 hour fuel moisture (%)	Average of 100 hour fuel moisture (%)	Average Herbaceous fuel moisture (%)	Average woody fuel moisture (%)
Temescal Fire Station	0-79	88.12	56.35	38.44	88.60	32.66	6.22	6.26	8.41	13.20	37.29	104.68
	80-89	93.35	56.86	27.92	78.49	24.29	9.98	4.50	6.37	11.22	15.22	91.54
	90-97	97.16	58.48	17.12	60.64	14.28	7.13	2.83	4.32	8.71	7.33	83.47
	98-100	98.59	58.71	15.24	54.59	13.64	10.61	2.59	3.80	8.10	5.37	79.71
Tonner Canyon	0-79	83.22	59.26	45.72	87.59	38.04	8.23	6.94	8.30	13.52	14.83	109.12
	80-89	88.70	64.30	21.90	48.80	17.50	9.20	3.30	4.40	9.20	3.30	95.00
	90-97	88.43	64.05	14.33	45.24	10.86	8.43	2.33	3.52	8.19	2.33	91.67
	98-100	89.58	68.33	9.58	31.92	6.33	10.50	1.67	2.67	7.00	1.67	83.58
Corona Fire Station	0-79	88.36	59.83	39.99	88.22	35.42	6.32	6.49	9.23	13.33	39.10	104.94
	80-89	92.73	61.26	31.03	78.63	28.36	11.89	5.24	8.54	11.48	27.54	96.86
	90-97	94.21	60.02	20.56	57.97	17.63	8.65	3.46	5.42	8.94	9.72	83.39
	98-100	94.12	59.32	18.00	57.86	15.50	9.22	2.94	4.32	8.72	5.80	70.66
Fremont Canyon	0-79	86.89	61.32	47.05	84.24	41.22	10.11	6.78	7.92	12.97	75.73	111.78
	80-89	92.00	66.10	23.40	49.20	16.50	13.00	3.60	4.40	8.30	50.60	114.10
	90-97	76.00	61.00	5.00	61.00	3.00	21.00	2.00	5.00	10.00	99.00	115.00
	98-100	90.00	74.00	6.00	28.00	5.00	22.00	1.00	3.00	8.00	59.00	107.00
Overall Average	0-79	86.65	59.19	42.80	87.16	36.83	7.72	6.62	8.46	13.26	41.74	107.63
	80-89	91.70	62.13	26.06	63.78	21.66	11.02	4.16	5.93	10.05	24.17	99.37
	90-97	88.95	60.89	14.25	56.21	11.44	11.30	2.65	4.57	8.96	29.60	93.38
	98-100	93.07	65.09	12.21	43.09	10.12	13.08	2.05	3.45	7.95	17.96	85.24

Table 3-4. Frequency of wind directions per RAW station and for the northern Santa Ana Mountains study region. These values correspond to the proportion of days that recorded the corresponding wind direction. Wind directions are the direction from which the wind is blowing.

Direction	Midpoint Direction (Degrees)	Temescal Fire Station	Corona Fire Station	Tonner Canyon	Fremont Canyon	Overall Average
Calm	N/A	0.0484	0.0355	0.0000	0.0204	0.0261
NE	45	0.0621	0.0200	0.0206	0.0204	0.0308
E	90	0.0145	0.0116	0.0187	0.0000	0.0112
SE	135	0.0208	0.0072	0.0187	0.1429	0.0474
S	180	0.0222	0.0084	0.1720	0.0408	0.0608
SW	225	0.0282	0.0469	0.6935	0.6939	0.3656
W	270	0.0260	0.5358	0.0449	0.0000	0.1517
NW	315	0.5053	0.3191	0.0150	0.0204	0.2149
N	0	0.2724	0.0155	0.0168	0.0612	0.0915

This environmental matrix summarized the probability of fire at any given year given the number of years without fire events. Using these two matrices, we simulate population trajectories and estimated intrinsic rate of population growth at different fire frequency regimes. In a second level of complexity we modified the base line population matrix to incorporate the effect of spatial heterogeneity observed in the field. Specifically, we assumed that the Tecate population was divided into two subpopulations growing in habitats with different survival and growth probabilities. With our base line population matrix we capture most of the key features of Tecate cypress' life cycle (Figure 3-2).

We based our demographic model on size categories because size is better predictor of cone production than age in this species (Figure 3-3, De Gouvaine and Ansary 2006). We defined size categories based on a combination of diameter and total height because it is common among Tecate cypress populations to find stunted individuals (Armstrong, 1966). We first defined seven size classes based on diameter and seven size classes based on height (Table 3-5). These classes were later used to define seven final size classes, which allow for individuals with similar biomass to be grouped together despite differences in a single indicator.

For each stage we estimated the annual per capita probability of surviving and growing, the probability of surviving and not growing, and the number of seeds produced. We followed the method of stage duration distributions described in Caswell (2001) to estimate size-specific transitions. We first estimated stage durations using the stage specific average height and the height versus age equation estimated from data provided by R.C. De Gouvaine (Figure 3-4). This data corresponds with the age of tree cores taken from the four different populations of Tecate cypress in Southern California. For details about this methods refer to De Gouvaine and Ansary (2006).

Given that the effect of fire on Tecate population is mostly through an increase in recruitment of seeds stored in the canopy seedbank, we included a seed category in the population matrix. Annual per capita fertility values were estimated in terms of number of seeds produced in each class. To estimate these values, we grouped the active adults detected in our 2009 census into size classes, and

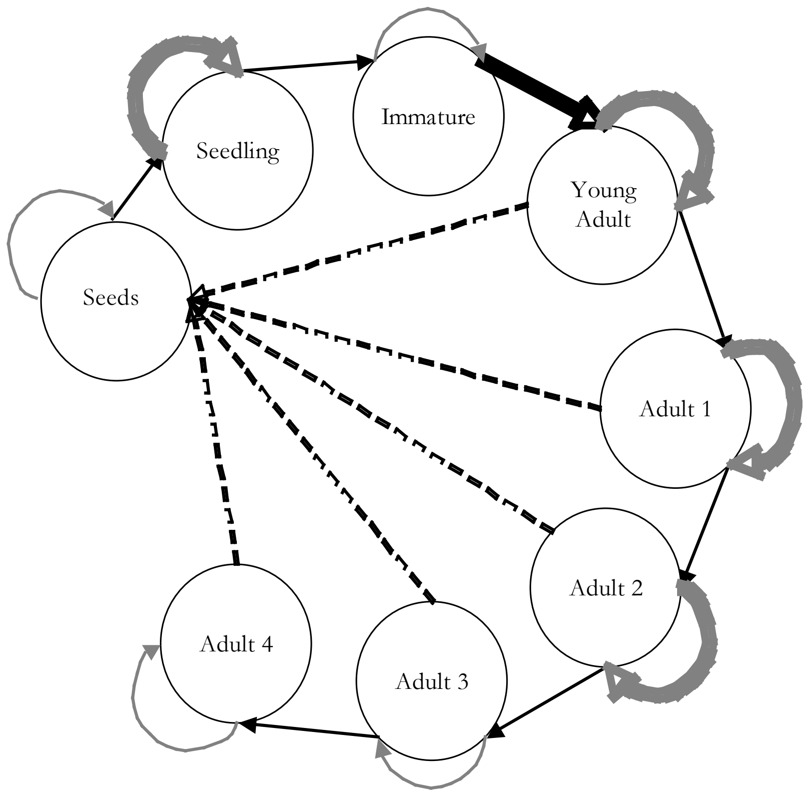

Figure 3-2. Baseline population model for Tecate cypress. Circles indicate stages in the Tecate cypress life cycle, and arrows indicate average probability transitions from stage to stage. Solid black arrows represent the probability that an individual grows from one stage to the other during a year; solid gray arrows indicate the probability that an individual survives and stays in the same stage. Finally, dashed arrows indicate the annual per capita number of seeds produced by reproductive cypress. Thicker arrows represent transitions that have higher values under improved growing conditions. Transitions under both environments are summarized in two population matrices used to simulate population trajectories (see Tables 3-5 and 3-6).

Table 3-5. Combination of height and diameter classes used to define final demographic size classes. Final classes are indicated in the central area of the table, and group different combinations of height and diameter classes. Initial height and diameter classes are modified from classes used by DeGouvain and Ansary (2006).

Height Classes	Diameter Classes						
	1 (< 0.5cm)	2 (0.5-2 cm)	3 (2-4.5 cm)	4 (4.5-7 cm)	5 (7-15 cm)	6 (15-30 cm)	7 (> 30 cm)
1 (< 0.5 m)	1	1	2				
2 (0.5-1 m)	1	2	2				
3 (1-1.5 m)		2	3				
4 (1.5-2 m)		3	3	4	5		
5 (2-3 m)		3	4	4	5		
6 (3-5 m)		4	4	5	5	6	
7 (5-10 m)					6	6	7
8 (>10 m)						7	7

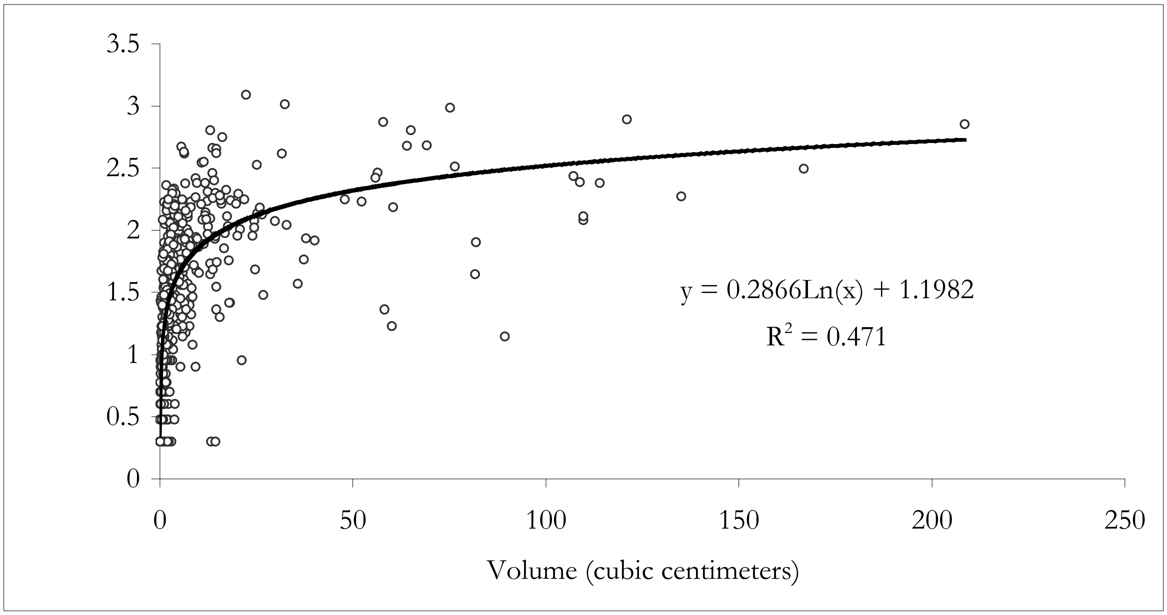

Figure 3-3. **Relationship between volume of Tecate cypress trees and cumulative cone production**. Data were collected from live adults during our 2009 census of the Santa Ana Mountains population. We calculated volume following the regression equation reported in Pillsbury et al. (1997) relating diameter and height with total canopy volume for Tecate cypress.

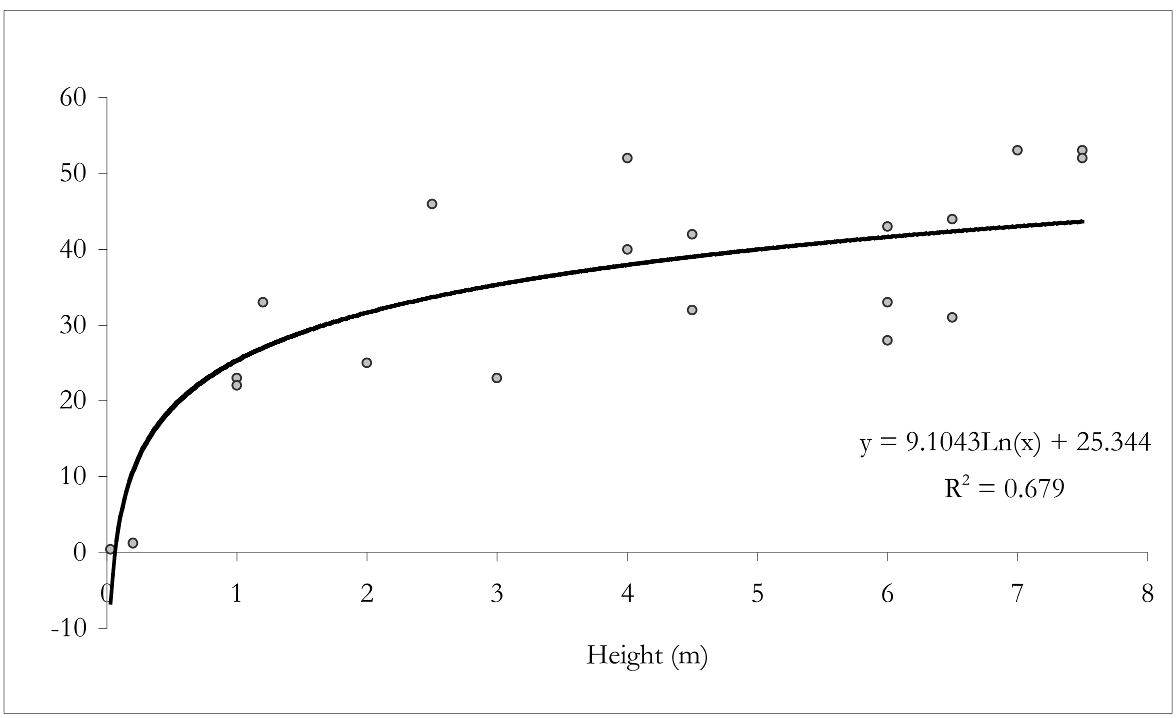

Figure 3-4. Relationship between height (m) of Tecate cypress and age (years). The equation was fit to data provided by R. De Gouvaine and used in De Gouvaine and Ansary (2006). The number of growing rings were counted using cores from trees in the four populations of Tecate cypress in southern California.

estimated the average number of cones per tree. This value was adjusted by the average age since first reproduction and number of seeds per cone (89 following De Gouvaine and Ansary, 2006) to obtain an estimation of annual seed production. Given that producing a cone takes at least 2 years (Armstrong, 1966), we divided the obtained number of seeds by two for the final annual per capita seed production (Table 3-6).

There is little information on seed viability and recruitment during years without fire. De Gouvaine and Ansary (2006) assumed a conservative value of 10% for seed survival and germination, which accounts for the high predation rate reported in other *Cupressus* species (70-90%; Battisti et al. 2003), and a germination rate of 7.5-50% in controlled conditions (De Magestris et al. 2001). We assumed a 10% survival of seeds in the seedbank to reflect potential predation and a very low recruitment during years without fire (0.1%). After a fire we assumed a germination probability of 0.1, as did De Gouvaine and Ansary (2006).

We modeled the effect of fire on population dynamics in two ways. First, we modified the baseline population matrix (Table 3-7) in order to account for the effect of fire on population transitions. We increased the germination rate from 0.001 to 0.1 following De Gouvaine and Ansary (2006); other transitions were not changed. Second, after a fire we instantly killed all immature classes and 0.8 of all adults; this percentage corresponds with the proportion of the population that was lost after the 2002 and 2006 fires (in 2002 areas with live adults was reduced from 242 to 60 ha). In this sense, we account for the possibility that areas escape fire in a similar way as detected during our survey. With this approach we are in the position to investigate not only the effect of changes in fire frequency, but also to explore the consequences of increasing tree survival during a fire.

In our simulations we used a simple population structure and a population subdivided into regions with different growing conditions (Tables 3-7 and 3-8). In order to estimate changes in growing transitions from site to site, we estimate the percent change in population structures from different areas, and apply this percent change to growth probabilities (σ_i) in Table 3-6; we then recalculated transition probabilities as before. We considered areas of improved growing conditions those areas with similar fire history, but which during our 2009 census had more and larger immature tress. These areas correspond to the lowest elevation portion of the current Tecate cypress population (Strata 1 and 3 from Section 2).

We projected Tecate population growth for a period of 200 years (Figure 3-5). At each time step during the projection, the environment was allowed to burn or not. To decide whether a population burns, we used fire hazard functions following (Moritz et al. 2003 and Markovchick-Nicholls 2007). The hazard functions used here correspond with Weibull probability functions estimated using the time since last fire in chaparral dominated shrublands in Southern California (Moritz et al. 2003). The Weibull function gives a year-specific probability of fire depending on the number of years since fire; we used this probability to estimate the environmental structure that corresponds with the long-term proportion of fire and non-fire years. Using this environment structure, we randomly selected whether a fire burns the population in a given year, which then indicates which population matrix to use. In order to investigate the effect of different fire regimes, we used six distinct functions with different expected fire return times (Table 3-9). Each projection was run 1000 times to approach the sample distribution of the intrinsic population growth and the stage distribution (Figure 3-5). We evaluate population persistence in terms of the terms of the average intrinsic growth rate.

Table 3-6. Summary of stage-specific parameters used to estimate population transitions. Censused individuals were grouped in size classes according to pre-defined diameter and height classes (Table 3-5). We used the equation generated with height versus age data points provided by De Gouvaine (Figure 3-2) to estimate stage duration. Following Caswell (2001) annual probability of growth to the next class (σ_i) was estimated as $1/T_i$. We also used the number of dead individuals detected during our 2009 census to estimate annual survival probabilities per class (γ_i). We used both σ_i and γ_i to calculate stage transitions for the base line population matrix. Per capita seed production was estimated using the total count of cones per class, the number of adults per class, the age since first reproduction (seven years following Dunn, 1986), and the average number of seeds per cone (89 following De Gouvaine and Ansary, 2006), and the fact that cone production takes two years to complete.

Class	Average Height (m)	Average Age (years)	Stage Duration	Censused Individuals	Dead Count	Survival	σ_i	γ_i	Average Number of Cones	Proportion of Adults	Per Capita Average Cone	Annual Seed Production
Seedling	0.300	14.379	14.379	1836	42	0.977	0.070	0.998				
Immature	0.800	23.308	8.930	2381	110	0.954	0.112	0.995				
Young Adult	1.900	31.184	7.875	291	10	0.966	0.127	0.996	3.813	0.896	3.417	6.288
Adult 1	2.900	35.033	3.850	350	84	0.760	0.260	0.931	21.326	1.000	21.326	33.853
Adult 2	6.100	41.803	6.770	361	54	0.850	0.148	0.976	82.377	1.000	82.377	105.329
Adult 3	7.300	43.438	1.635	126	14	0.889	0.612	0.930	238.145	1.000	238.145	290.834
Adult 4	10.000	46.303	2.865	1	0	0.990	0.349	0.996	535.000	1.000	535.000	605.736

Table 3-7. Baseline population matrix for Tecate cypress under average growth conditions. This is the numeric representation of Figure 3-2. Gray cells represent existent transitions during the Tecate cypress life cycle. Diagonal elements represent average survival probabilities and were calculated as $(1-\gamma_i)*\sigma_i$ from Table 3-6. Subdiagonal elements represent average growth probabilities and were calculated as $\gamma_i*\sigma_i$. Transitions on the top row represent annual per capita seed production. All transitions were estimating using data from the 2009 census of the Santa Ana Mountains population.

Stage	Seed	Seedling	Immature	Young Adult	Adult 1	Adult 2	Adult 3	Adult 4
Seed	0.100	0.000	0.000	6.288	33.853	105.329	290.834	605.736
Seedling	0.001	0.929	0.000	0.000	0.000	0.000	0.000	0.000
Immature	0.000	0.069	0.883	0.000	0.000	0.000	0.000	0.000
Young Adult	0.000	0.000	0.111	0.869	0.000	0.000	0.000	0.000
Adult 1	0.000	0.000	0.000	0.126	0.689	0.000	0.000	0.000
Adult 2	0.000	0.000	0.000	0.000	0.242	0.832	0.000	0.000
Adult 3	0.000	0.000	0.000	0.000	0.000	0.144	0.361	0.000
Adult 4	0.000	0.000	0.000	0.000	0.000	0.000	0.569	0.649

Table 3-8. Population matrix for Tecate cypress in areas with improved growth conditions. Shade cells correspond with transitions with greater values than the base line population matrix. These areas showed higher growth values in most life cycle stages. Reproductive values were assumed to be similar for both transition matrices.

Stage	Seed	Seedling	Immature	Young Adult	Adult 1	Adult 2	Adult 3	Adult 4
Seed	0.100	0.000	0.000	6.288	33.853	105.329	290.834	605.736
Seedling	0.001	0.917	0.000	0.000	0.000	0.000	0.000	0.000
Immature	0.000	0.083	0.927	0.000	0.000	0.000	0.000	0.000
Young Adult	0.000	0.000	0.079	0.868	0.000	0.000	0.000	0.000
Adult 1	0.000	0.000	0.000	0.132	0.668	0.000	0.000	0.000
Adult 2	0.000	0.000	0.000	0.000	0.327	0.771	0.000	0.000
Adult 3	0.000	0.000	0.000	0.000	0.000	0.227	0.376	0.000
Adult 4	0.000	0.000	0.000	0.000	0.000	0.000	0.569	0.644

Table 3-9. Weibull probability functions used during the population projections. Weibull distributions are defined by a scale parameter that specifies the scaling of the distribution and a shape parameter that controls the shape of the curve. Both parameters combine in the calculations of expected return intervals and its variance. At a constant shape parameter large scale parameter yield large expected values and variance. We used the same Weibull functions used by Markovchick-Nicholls (2007), which are adjusted versions of functions fitted by Moritz et al. (2003) to fire intervals at Los Padres National Park, California. Fire regimes refer to different fire return intervals; they are ordered from longest to shortest return interval.

Fire Regime	Scale parameter	Shape parameter	Expected return interval	Variance of return interval
1	62.9	1.37	57.31	24.037
2	50.1	3.33	44.961	20.845
4	39.5	3.33	35.45	16.182
3	41.5	2.06	36.73	18.073
6	10	1.5	9.02	3.2
5	20	1.5	7.38	18.05

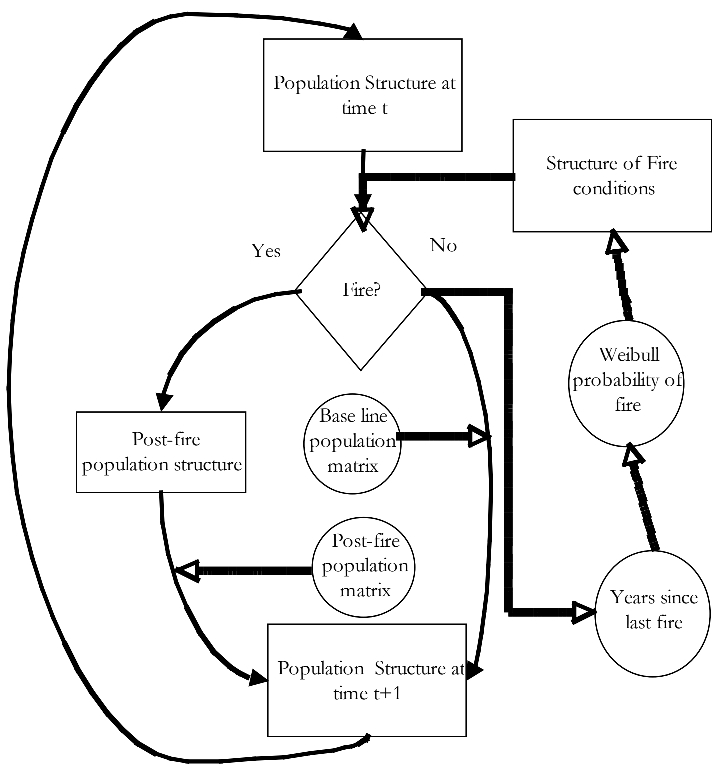

Figure 3-5. One year population projection for the Santa Ana Mountains population of Tectate cypress. At each time interval during the simulation, the probability of fire is given by a Weibull probability of the number of years since last fire. This probability defines a distribution of fire conditions (burned and non-burned conditions), from which a condition is randomly selected and used to define the appropriate population matrix. We projected the population over 200 years, and ran 1000 iterations.

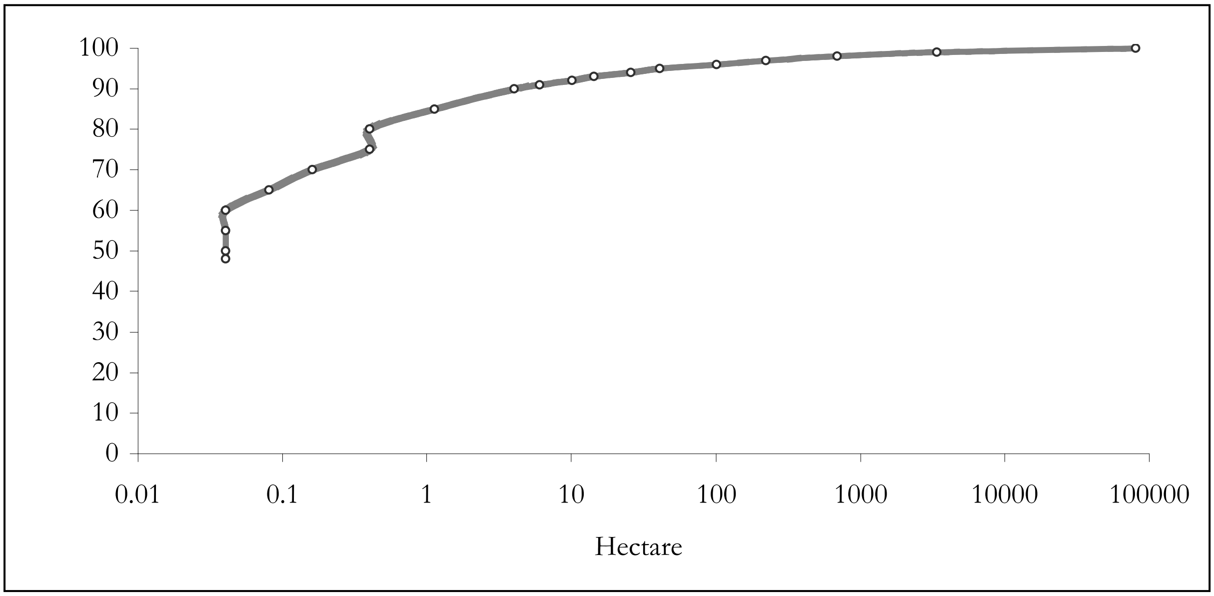

Figure 3-6. Size percentiles of fires in Southern California obtained from historical fire occurrence data from Cleveland National Forest and Orange County. The X axis indicates in a logarithmic scale the size of burned area in hectares; the y axis corresponds to the percentile associated with that area.

Results and Discussion

Fire Risk Assessment

Most fires occurring in the northern Santa Ana Mountains and Orange County are small fires of less than 0.1 ha. Only 20% of the reported fires were larger than 1 ha (Figure 3-6). Most of the small fires occurred on or around urbanized areas while large fires encompassed less populated and more isolated areas.

Flammap burn probability maps show the expected number of fires burning in an area for 1000 simulated fires with random ignition points. These maps are useful in evaluating the effect of topographic variables on fire behavior. We performed simulations with four increasingly severe weather conditions in combination with eight wind directions. The estimated weighted number of fires shows that areas with Tecate cypress have very similar burn probabilities (Figures 3-7 and 3-8). Independent of the severity of environmental conditions, areas close to Tecate cypress populations with southeast slopes facing Fremont Canyon have the highest susceptibility to burn. In the past, Tecate cypress were reported growing in these areas, but the last two fires (2002 and 2006) killed all cone bearing trees. Similar to this Fremon Canyon area, high elevation areas on the northeastern flank of Santa Ana Mountains (in the Cleveland National Forest) also show a high tendency to burn. These areas include patches of Tecate cypress that grow along the dirt road at the northern end of the Cleveland National Forest. Besides these two areas, high fire counts were also found along the eastern flank of Coal Canyon and southwest of the study region along highway 241. Increasingly severe environmental conditions do not substantially alter the pattern of fire probabilities (Figures 3-7 and 3-8). As conditions become more severe, fire counts increase and the spatial distribution becomes less patchy. Across severity scenarios, areas with high fire counts remain constant; which is expected given the strong effect of topography on fire spread. Changes in fire susceptibility are larger when environmental conditions change from normal to rare (Table 3-10) given that areas with high susceptibility under normal conditions showed greater increases in fire counts under rare conditions than the changes observed between rare and severe conditions. In this case, the number of fire counts increased in a large portion of Gypsum Canyon, suggesting that susceptibility of these areas is similar.

Under Santa Ana conditions, there was a similar spatial pattern of areas with a high susceptibility to burn as when other wind directions were considered, but with a higher number of fires in those areas during Santa Ana conditions (left panel in Figure 3-9). Areas on the northeastern flank of the Santa Ana mountains close to Corona, and areas on the upper Gypsum canyon showed much higher fire numbers than when all possible wind directions are considered under extreme environmental conditions (lower left panel Figures 3-8 and 3-9). In areas where Tecate cypress has been reported and is currently present, fire counts tended to be higher on the Irvine Ranch lands, especially at the bottom of Gypsum canyon (Figure 3-9). Nevertheless, at the scale of our simulation, areas where Tecate cypress is present show low fire counts relative to other areas, such as Fremont Canyon. We found little correlation between areas with low fire counts and areas that escaped the last fires and retain cone bearing Tecate cypress trees (refugia). We found refugia in open areas with smooth topography and along ravines, although refugia with the largest Tecate cypress trees are along ravines at low elevations. These areas did not show different fire counts than other sections of the Tecate cypress population, which implies that the level of resolution of this analysis is insufficient to predict areas with low susceptibility to fire. Under Santa Ana conditions, areas on Irvine Ranch land and in upper Coal Canyon in the Coal Canyon Ecological Reserve showed higher susceptibility to burn (left panel in Figure 3-9). It is worth noting that these areas correspond to areas with the largest numbers of live adults, as in the lower portion of Gypsum canyon, or to areas with high densities of seedlings.

The lack of detectable differences in fire risk within areas currently supporting Tecate cypress limits the extent to which we can incorporate fire risk into our population model. In addition to burn probabilities, we can differentiate between areas that recently burned and areas than did not burn based on our field data. During our fire simulations we explored the sensitivity of population growth rates to changes in percent of unburned areas (see population dynamics methods).

Since our simulations are based on random ignitions, our analysis emphasizes the effect of topographic features on fire behavior and is unlikely to reflect actual burn probabilities. This is because ignitions are non-random in location and areas with higher probability of ignition are likely to have a higher burn probability. Thus, the number of fires simulated with Flammap is a useful metric for comparing susceptibility, but is not an estimation of actual fire risk. In a coarser scale study, Anderson (2009) estimated fire susceptibility on Irvine Ranch lands and constrained fire ignitions to areas close to major highways (Highway 241 and 91). His results demonstrated that the northern extreme of the Santa Ana Mountains with Tecate cypress on Irvine Ranch lands had higher fire susceptibility than southern areas that were closer to the city of Irvine (Anderson 2009). In contrast, our results indicate that at a smaller scale, areas south of the current population extent and at higher elevations are more susceptible to fire and that generally the region has a higher susceptibility.

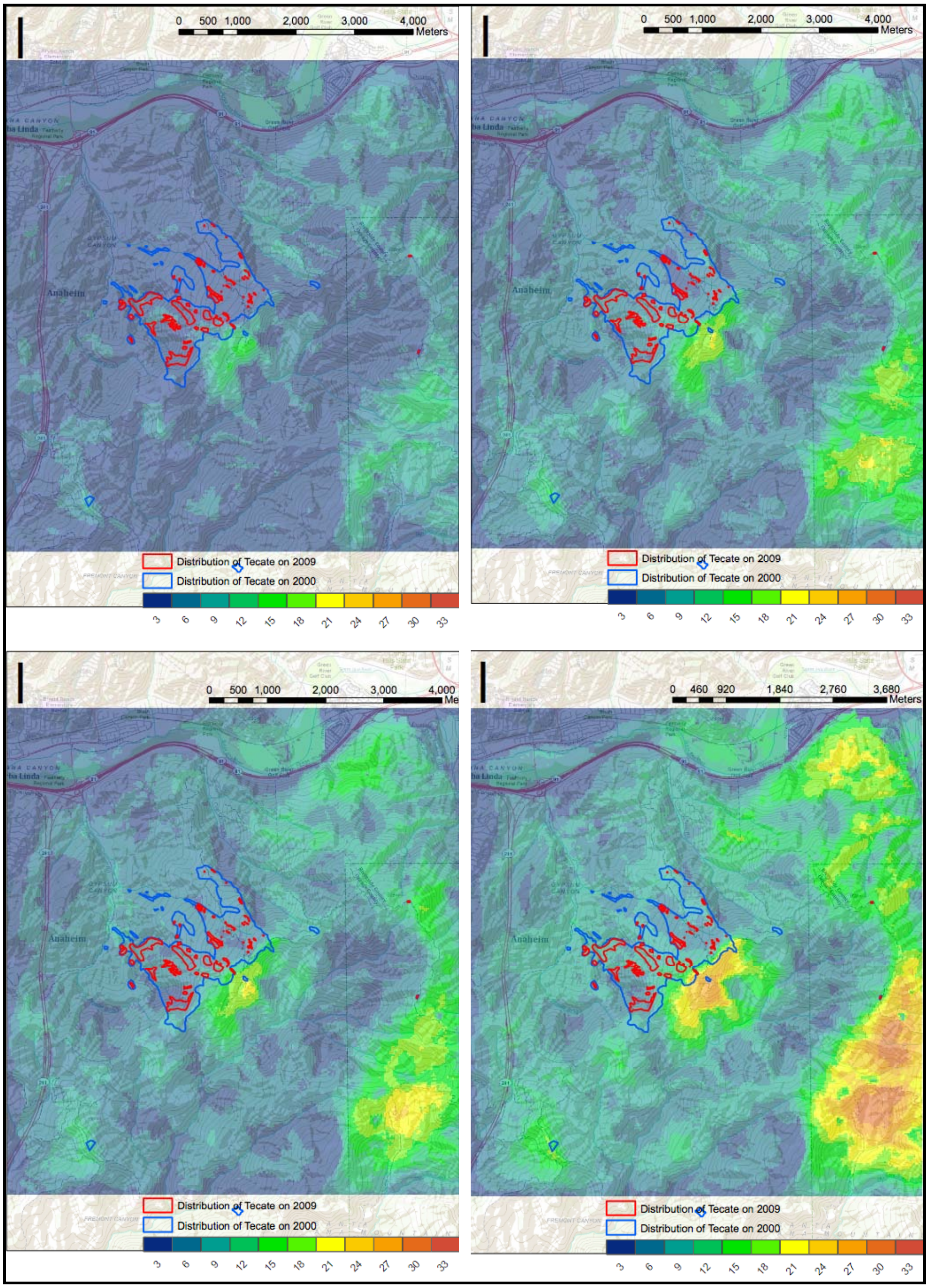

Figure 3-7. Burn probability maps for northern Santa Ana Mountains Tecate cypress produced with Flammap under different environmental severity conditions. Each map represents the result of 1000 iterations of fire with random ignition locations. Numbers for each cell show total number of times the cell burned during the simulation. These numbers can be interpreted as susceptibility of that particular area to fire. Each panel represents different weather conditions described in Table 3-3: The upper left figure corresponds to Normal conditions, the upper right to Rare conditions, the lower left to Severe conditions, and lower right to Extreme conditions. Study area is located in the USGS Black Star Canyon 7.5 minute quadrangle.

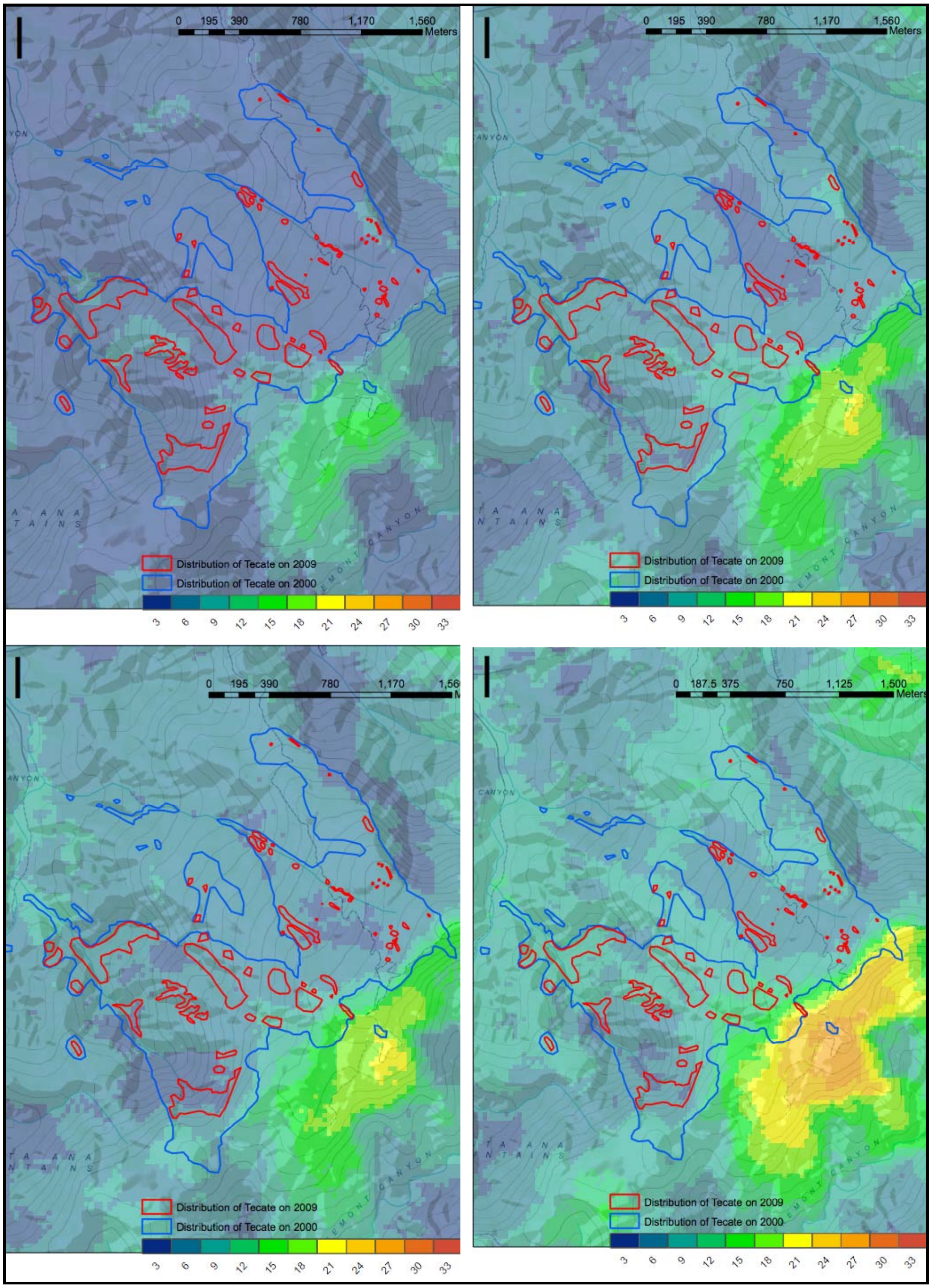

Figure 3-8. Close-up view of northern Santa Ana Mountains Tecate cypress stand fire counts from burn probability maps produced with Flammap. The number associated with each cell represents the number of times that cell burned during the simulation of 1000 fires with random ignition locations. Each panel represents different environmental conditions described in Table 3-3. The upper left figure corresponds to Normal conditions, the upper right to Rare conditions, the lower left to Severe conditions, and the lower right to Extreme conditions. Study area is located in the USGS Black Star Canyon 7.5 minute quadrangle.

Table 3-10. Average number of fires detected throughout the current and historic distribution of Tecate cypress in the Santa Ana Mountains. The number of fires represents the number of times an area is expected to burn out of 1000 fire simulations with random ignition points. Simulations were run separately for different environmental conditions.

Area	Weather Condition (Percentile)	Average Number of Fires/1000 Ignitions	Standard Deviation	Maximum Number of Fires/1000 Ignitions
Tecate Distribution in 2000	Normal: 0-79%	2.05	1.256	11.39
	Rare: 80-89%	4.68	1.98	17.94
	Severe: 90-97%	4.52	2.06	18.17
	Extreme: 98-100%	6.83	3.06	25.82
Tecate Refugia in 2009	Normal: 0-79%	1.99	0.96	8.35
	Rare: 80-89%	4.46	1.58	13.91
	Severe: 90-97%	4.122	1.42	13.90
	Extreme: 98-100%	6.38	2.35	20.72

Population Dynamics

The Tecate cypress population in the Santa Ana Mountains showed a strong potential for recovery following the 2006 fire. Population dynamics estimated from data collected in 2009 indicate that under the assumption that life history transitions remain constant, the Tecate cypress population has a slightly positive annual population growth rate (λ=1.0140 for regular growing conditions and λ=1.0288 for improved growing conditions; values higher than 1 indicate positive population growth). These results are similar to estimations made by De Gouvenain and Ansary (2006) in 2003 following the 2002 fire (λ = [0.88 -1.096]). This result is in part driven by large counts of seedlings and saplings in the second and third size classes, the high reproductive potential of surviving trees, and the high survival probabilities estimated from our census data (Table 3-6). The importance of these classes is evident in the stable stage distribution that illustrates the hypothetical population structure under average and improved growing conditions (Figure 3-10), and after the population is projected for several years.

Under constant conditions (Table 3-7), the seedbank dominates the population structure, followed by small individuals. The adult classes with the highest contribution to population growth are classes 5, 6, and 7, given that these classes showed the highest reproductive values (Figure 3-11). This value is an estimation of the importance of classes over the long-term, and considers not only the potential contribution in number of seeds, but also the probability of survival and growth into each class. In the particular case of Tecate cypress, reproductive values consider the tendency of an increase in cone production with size, and a decreased survival probability in the intermediate to large size classes (Table 3-6). This decline in the large classes explains the decline of reproductive value, despite an increase in cone production.

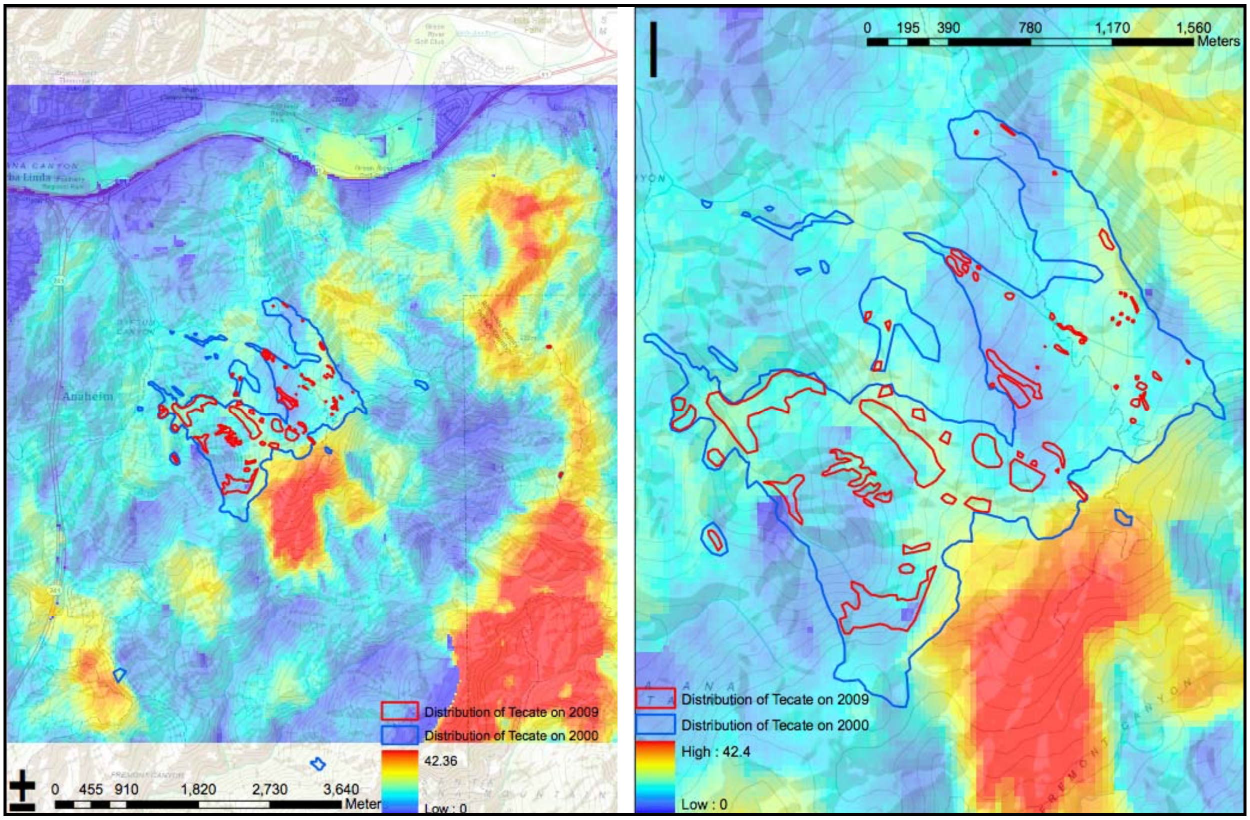

Figure 3-9. Expected number of fires in the northern Santa Ana Mountains during Santa Ana wind conditions. The panel on the left indicates the expected number of fires out of 1000 fire simulations with random ignition locations. To approximate Santa Ana conditions, we used extreme weather conditions (Table 3-3), winds with north and northeastern origins, and an extreme wind speed of 25 miles per hour. The panel on the left is a close-up of the areas where Tecate cypress is currently present or has occurred historically.

Results were similar when we considered the population matrix under improved growing conditions (Table 3-8) for Tecate cypress (right panel in Figures 3-10 and 3-11). Although the estimated annual population growth rate is slightly higher, stable size population structure and reproductive values were similar. This suggests a low sensitivity of the population to changes in growth conditions in the first size classes.

This first approximation to population dynamics assumes that conditions will remain constant and that the population will not experience fires. When we include the effect of fire, population growth rate will fluctuate around a long-term mean because of the effect of environmental stochasticity. Although this initial fluctuation is strong and reflects the influence of initial population conditions, variability in population growth quickly decreases. The influence of initial conditions is stronger with fire regimes that have intermediate expected fire return inervals (Figure 3-12). This is probably due to the fact that at extremes fire return intervals surviving individuals have either a very low or very high recovery probability following a fire. At intermediate fire return intervals, variation in population growth reflects variability in the effective population following a fire and in the distribution of classes with different reproductive values.

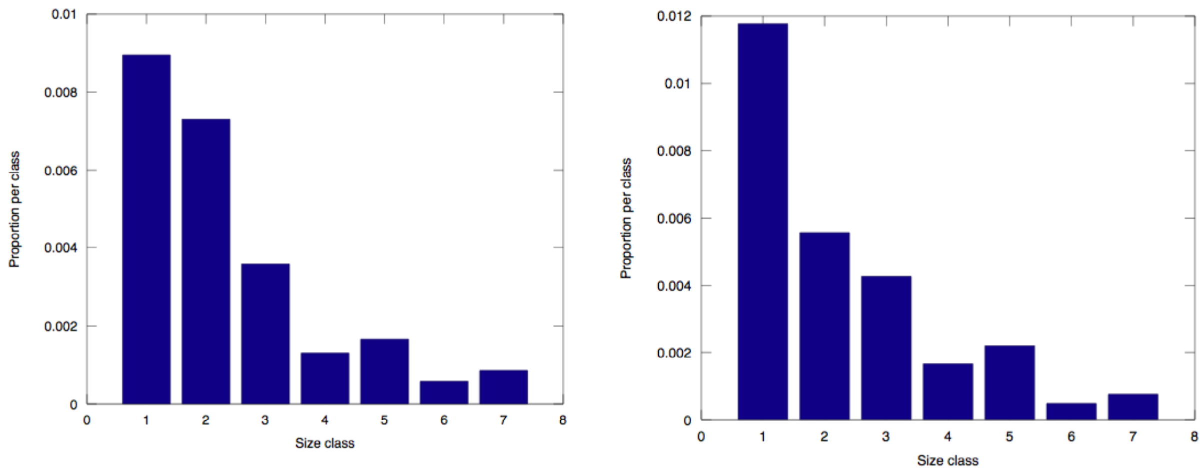

Figure 3-10. Stable size population structure of Tecate cypress excluding seed bank size under two different growing conditions. The figure on the left shows that growth probabilities are usually high among size classes under improved growing conditions (Table 3-8); this corresponds to areas 1 and 3 of our survey. The graph on the right represents average growing conditions (Table 3-7). Both graphs represent Tecate cypress population structure once population growth has stabilized over the long run.

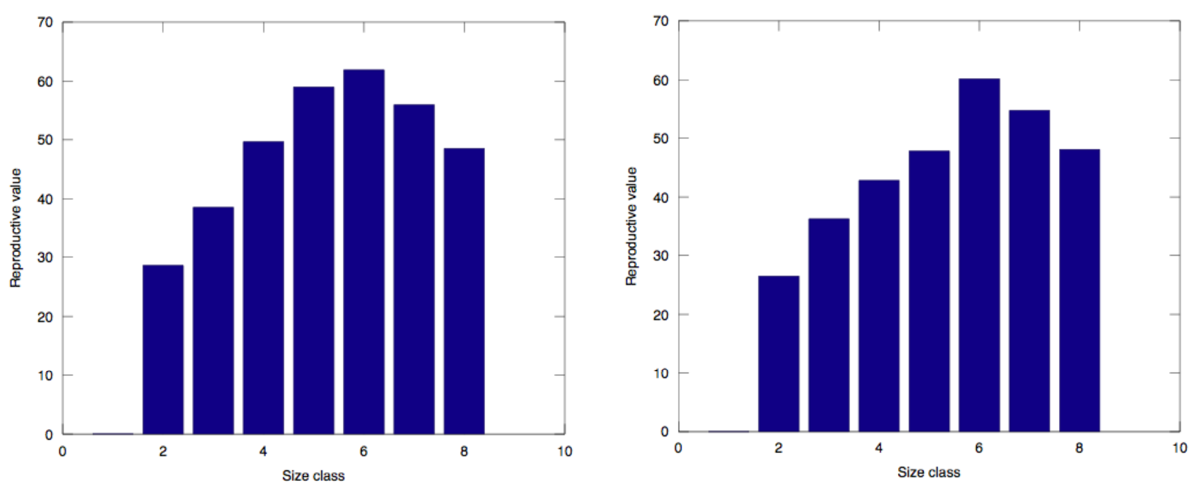

Figure 3-11. Reproductive value (long term average per capita number of seeds) of different size classes for Tecate cypress population under different growing conditions. The graph on the right represents average growing conditions (Table 3-7), while the graph on the left represents improved growing conditions (Table 3-8). Reproductive value measures the long-term contribution of size classes to total population growth, and considers not only the reproductive potential of each class, but the probability of survival and growth.

Population growth rate decreased with expected fire return interval, consistent with findings reported by De Gouvaine and Ansary (2006). Intrinsic population growth is negative when we used fire hazard functions with expected return intervals of less than 20 years and is positive for probability functions with expected values of more than 30 years, irrespective of their variance (Figure 3-13). This trend is explained in part by the approach we took in modeling Tecate cypress's life history. In our survey, we detected cone-bearing trees that belonged to size class 3, which corresponds with individuals with an average age of 31 years, but in which some individuals may have started reproducing at an earlier age. Maturation times are highly correlated with growing conditions and in this population the youngest adults were observed in open areas with very low vegetation cover and where the fire did not burn. This variation in age of maturity makes the Tecate population more resilient to fire effects than originally considered by Dunn (1986) who described reproductive potential as a function of age in which Tecate individuals have peak reproduction between 35 and 40 years of age.

Our results also differ from those reported by Markovchick-Nicholls (2007). Similar to Dunn (1986), Markovechick-Nicholls modeled Tecate cypress's life cycle as highly dependent on age and used Dunn's equation for the analyses. In addition, Markovchick-Nicholls explicitly incorporated density dependence in her model, which inevitably makes populations more sensitive to fire effects. Density dependence effects on cone production result in a reduction in the amount of seeds produced per individual at each size class as the population becomes larger. As a consequence, the portion of reproductive value contributed by the first class will be lower than the model predicts, making the population less resilient to fire frequencies of less than 30 years. Thus, density dependence can decrease seedbank size to levels that do not allow population recovery after a fire. Given that we want to understand fire recovery potential of Tecate cypress independent of environmental limitations, in this first approximation we assumed density independent mortality.

The Tecate cypress population is more sensitive to changes in the percentage of seeds available after a fire than to the percentage of survivors. We investigated the sensitivity of Tecate population to the percentage of individuals killed during a fire. We predicted the Tecate cypress population using a fire hazard function with a mean return interval of 35.5 years and increasingly severe fire effects. This effect included a reduction in the percentage of survivors (Figure 3-14) and seeds available after a fire (Figure 3-15). Given the high levels of recruitment after a fire, the Tecate cypress population will recover even when all individuals are killed during a fire; nevertheless this resilience is highly dependent on the fire regime. In our case, a 35 year return interval will allow survival of seeds to reach reproductive maturity and contribute to population recovery. On the other hand, intrinsic population growth will drop below recovery capacity (lower than 0) whenever the percentage of seeds available after a fire drop below 70% of the seeds contained in the seedbank. In this case, even though the fire return interval favors reaching reproductive maturity, the number of seeds will not be enough to maintain positive population growth.

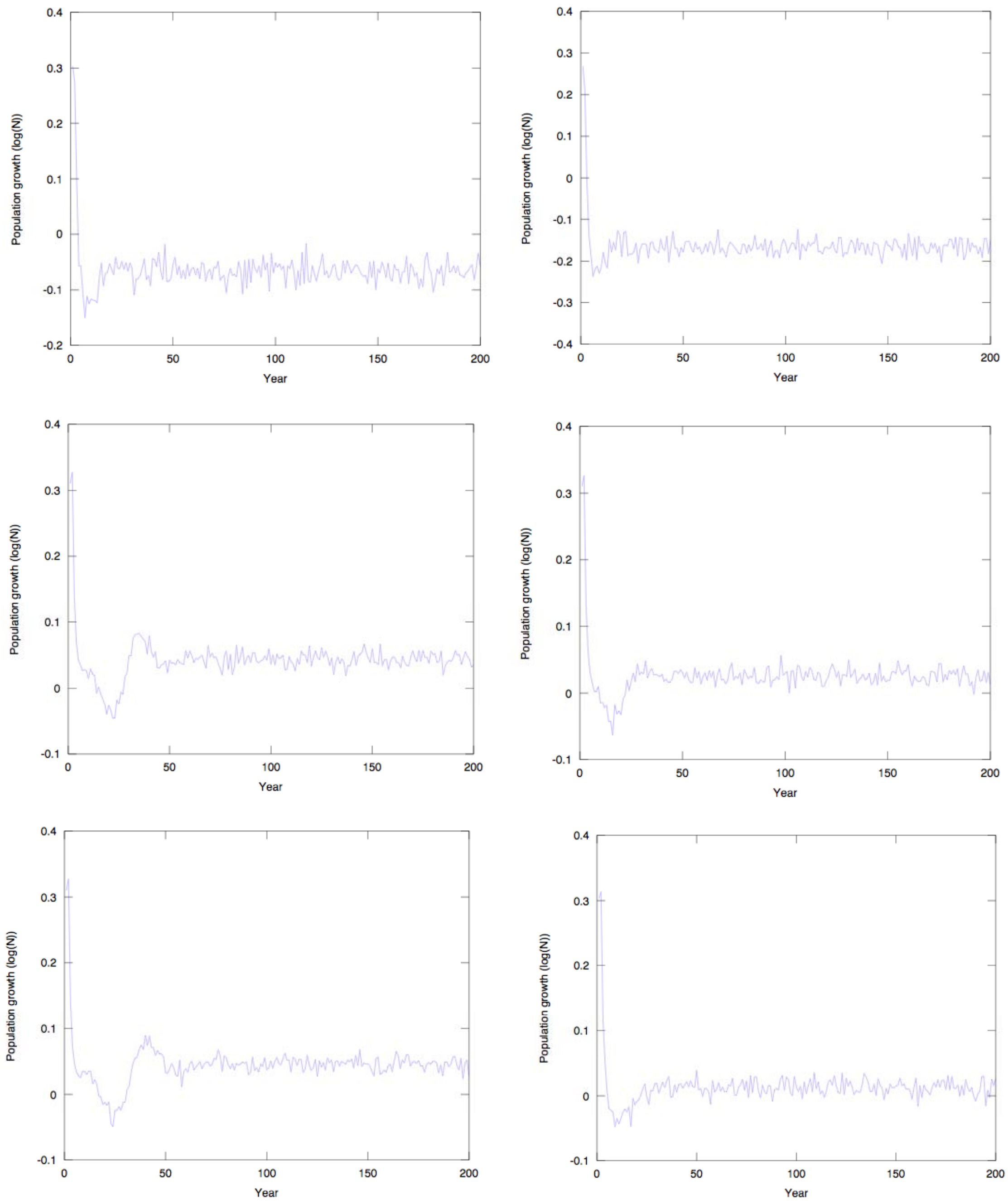

Figure 3-12. Changes in time series of intrinsic population growth rate (individuals per year) with different fire regimes. Each panel represents mean intrinsic population growth from 1000 projections of 200 generations using the population matrix for regular growth conditions (Table 3-7). From left to right and top to bottom panels correspond with fire regimens with increasingly higher mean return interval (UL=7.38 years; UR=9.02 years; ML=35.45 years; MR=36.7 years; LL=44.96 years; LR=57.31 years)

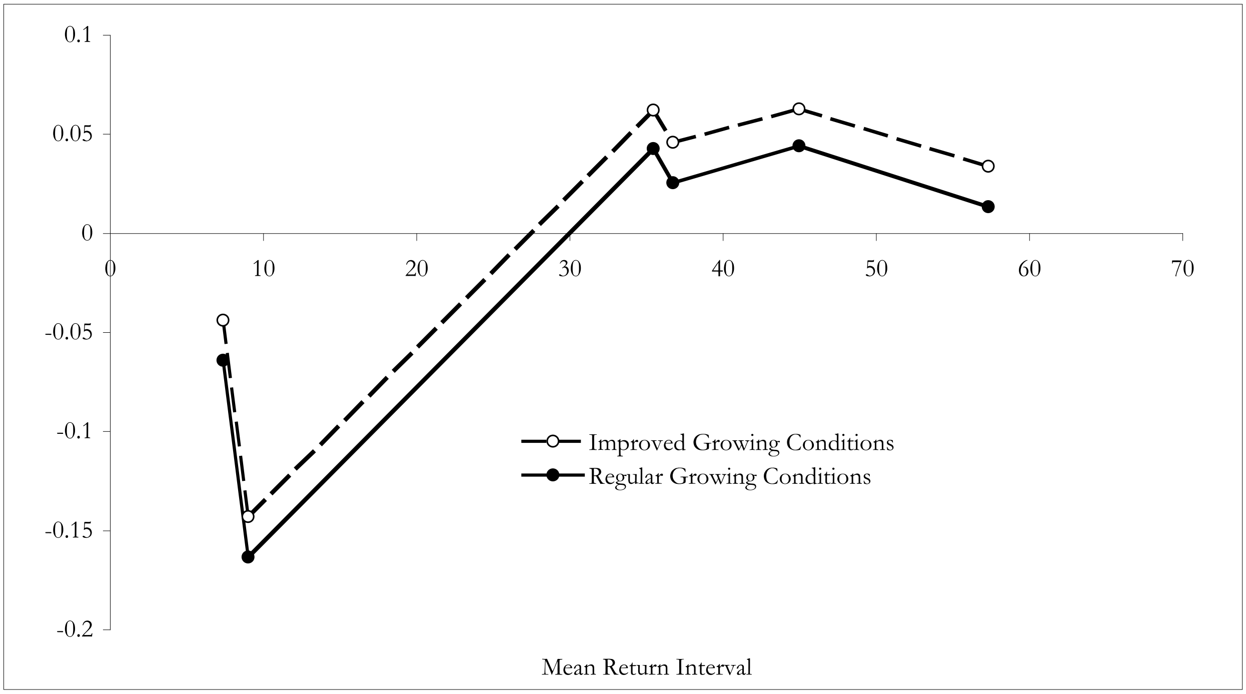

Figure 3-13. Effect of fire regime on intrinsic population growth rate (individuals per year). We simulated population growth of Tecate cypress over 200 generations using a matrix population model with a stochastic environment. Stochasticity is given by the probability of fire. We ran simulations with different mean expected fire return time and for each simulation estimated the expected intrinsic population growth over 1000 iterations. We also used population matrices that depicted different growth conditions.

Conclusions and Recommendations

With this study we identified that areas where Tecate cypress is currently present or it has been reported have a similar susceptibility to burn. Although during our 2009 census we identified several areas that did not burn in the last two fires, in our fire behavior simulations these areas have similar fire susceptibility to areas that recently burned. We found that these areas are mostly associated with ravines or strong slopes. At a coarser scale of observation, areas on Irvine Ranch land showed consistently higher fire counts than areas in the Coal Canyon Ecological Reserve. Nevertheless, this difference is reduced with more severe environmental conditions, under which, several areas on the Coal Canyon Ecological Reserve showed similar fire counts as areas on Irvine Ranch Land. This lack of variability in predicted fire susceptibility among areas with different fire history limits the amount of information we can incorporate into our population viability analysis. Thus, we limit the consideration of fire's effect on the spatial structure of Tecate population to the percentage of individuals killed after a fire event and assumed that the entire population has a similar susceptibility to fire.

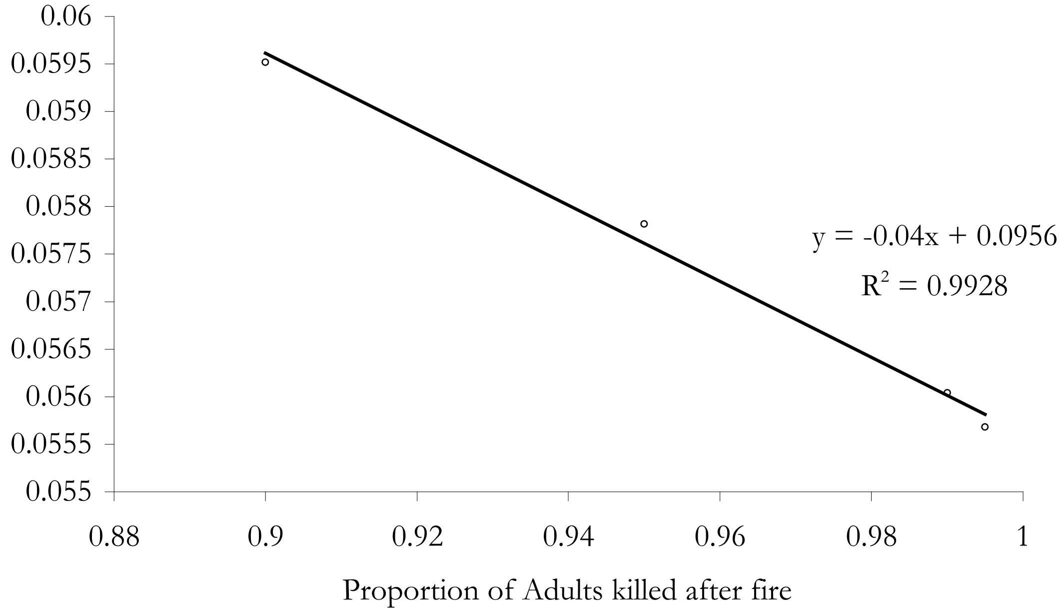

Figure 3-14. Changes in Tecate cypress long-term population growth rate (individuals per year) with increasingly severe fire effects. Fire effects are modeled as the proportion of adults killed after a fire in a model with expected fire return interval of 35 years. Each value represents the mean over 1000 population projections of 200 years.

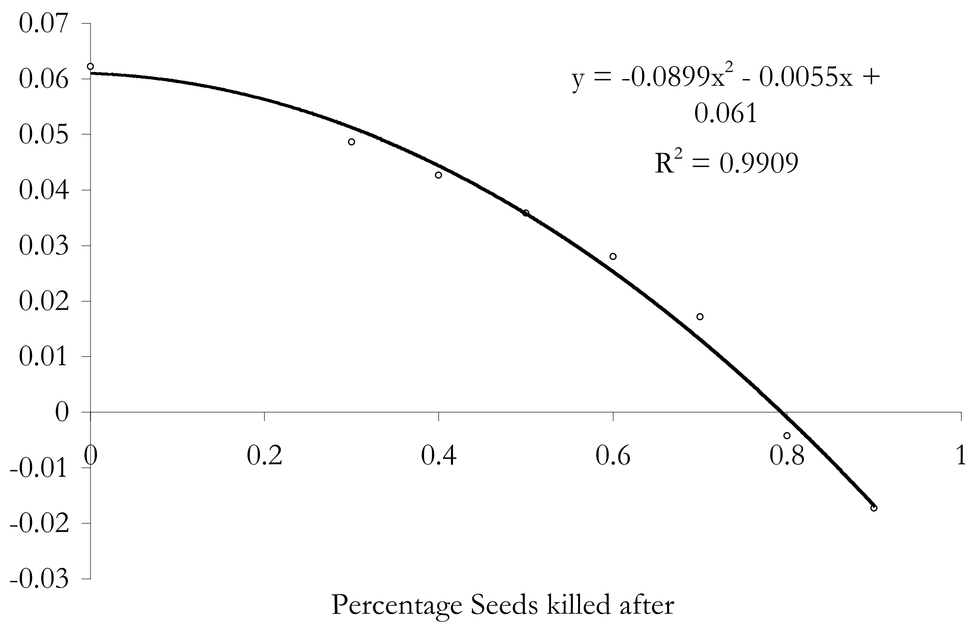

Figure 3-15. Changes in Tecate intrinsic population growth rate (individuals per year) with increasingly severe fire effects. Fire effects were modeled as the percentage of seedlings killed after a fire in a model with a fire return interval of 35 years. The percentage of adults killed after a fire was set to 80%. Each value represents the mean over 1000 population projections of 200 years.

Using a size-based environmentally stochastic model, we identified several key features of the Tecate cypress population with strong implications for its conservation status. We found that life history transitions of this species will promote a stable or slightly positive population growth whenever conditions are constant. In particular, we identified that current levels of cone and seed production are appropriate for self-replacement, even when seed mortality and germination are as low as 10% and 0.1% of the seedbank, respectively. Although this result is based on the assumption that recruitment of this species is independent of fire events and that cone bearing individuals are fully connected with areas where recruitment is favored, the fact that we detected positive annual population growth with such a small percentage of annual recruitment suggest a potential benefit of investing in promoting recruitment during years without fire. In fact, De Gouvaine and Ansary (2007) estimated an annual recruitment rate of 230 seedlings, which yielded an annual population growth rate close to one. Our estimates are of the order of at least one seedling per reproductive adult every two years.

These findings are based on strong assumptions about cone production and population connectivity. Cone production changes with time and dispersal rates are the two aspects of the Tecate cypress life cycle that are not well studied. Our recommendation is to explore in more detail the year-to-year variability in cone production, seed viability and recruitment during years without fire. In general, monitoring the Tecate cypress population over the years will greatly improve our understanding of the life history of this species. With long-term data it will be possible to have a much better estimation of the true sensitivity of this population to changes in environmental conditions and fire regime.

We found that differences in growth conditions have little effect on long-term population dynamics. Although during our 2009 census we identified areas with the same fire history transitions but with different population structures, these differences do not translate into significantly different population characteristics. Despite these results, it is important to accurately estimate variability in growth conditions throughout the original extent of Tecate cypress. If a feasible conservation strategy implies devoting resources to establish a focal population throughout the northern end of the Santa Ana Mountains, it will be advisable to detect the lower tolerance limit on which Tecate cypress populations show stable or positive population growth. In fact, our current analyses are preliminary for this purpose and solely based on current population structure at specific locations; we did not explicitly measure growth rates across the landscape. Given that long-term population dynamics are highly sensitive to survival transitions in the first size classes, we recommend extending the basic research to fully evaluate the effect of different habitat conditions on life history transitions of this species. Nevertheless, a general strategy in the absence of such information would be to give priority to management plans that improve growth and survival of already established juveniles.

When fire stochasticity is included in the model we found that Tecate population growth will drop to negative values under fire regimes with expected fire return intervals of less than 35 years. This result roughly agrees with previous estimations of optimal fire return interval for Tecate cypress (35-44 yeas from Dunn, 1986; Markovchick-Nicholls, 2006; and De Gouvaine and Ansary, 2007). The implication of this result is that management strategies should be designed in such a way that most Tecate individuals will not experience fires for at least 30 years and can reach reproductive age to ensure seed availability in case of a fire.

4.0 HABITAT ASSESSMENT

The current distribution of Tecate cypress in the Santa Ana Mountains is restricted to an area of 235.5 hectares in Gypsum and Coal Canyons (Figure 2-2). Although the historic distribution was relatively uniform throughout this area, frequent fires in the last 27 years have strongly reduced adult densities and areas of active recruitment. During a survey conducted between March and April 2009, we identified 75 patches with adult individuals; the total area with live adults was 35 ha. We also identified areas of active recruitment of approximately 87 ha. Areas with cone bearing adults are small and sparsely distributed throughout the landscape, while areas of active recruitment are concentrated in the upper portion of Coal Canyon. Thus, the current distribution of Tecate cypress is characterized by a strong segregation between the location of adult and seedling trees. The purpose of this study is to identify potential areas for recovery of this species by estimating habitat suitability throughout the northern extreme of the Santa Ana Mountains.

Methods

We calibrated a predictive model that relates Tecate cypress occurrences with environmental variables to produce habitat suitability estimations throughout the landscape. For this purpose, we used the program MaxEnt (Maximum Entropy model; Phillips et al. 2004, 2006a, b). The general approach of this program is to estimate a probability distribution for occurrence of a species at given locations. When we do not have information about this probability distribution our best estimate is to assume that the species has the same probability of occurring at any location, which corresponds to a uniform distribution. When we have environmental variables measured in areas where the species is present and absent, we have more information about where this species is likely to occur. With this information we can impose some restrictions on which probability distributions are likely to describe the species occurrence. MaxEnt searches for the probability distribution of maximum entropy (closest to a uniform distribution) that is subject to constraints reflecting our knowledge of the real probability distribution (Phillips et al. 2006a).

When applied to habitat modeling, this approach assumes that our knowledge of the true distribution is captured by expected values (e.g. mean or variance) of several environmental variables, which implies that the true probability distribution can be expressed as a function of environmental information. Searching for the probability distribution with maximum entropy is equivalent to searching for the probability distribution that maximizes the likelihood of presence of the species in the sample points where the species is currently present (Della Pietra et al. 1997). The approach to modeling is to estimate the coefficients associated with several environmental functions (features) that will yield the maximum likelihood when the likelihood function is constrained to approach the empirical average of environmental conditions. Because MaxEnt works with presence-only data, the actual probability distribution estimated by the program should be interpreted as an index of habitat suitability (Philips et al. 2006a). MaxEnt usually yields more accurate and precise estimations than most other presence-only habitat modeling techniques (Elith et al. 2006).

Locations and Environmental Variables

We derived presence-only data from our survey of Tecate cypress in the northern Santa Ana Mountains. This survey was conducted throughout an area of approximately 200 hectares. The extent of the surveyed area was defined as the region where Tecate cypress is currently present, or has been recorded in the past (Figure 2-2). The suitability predictions from MaxEnt were calculated over a larger area in the northern portion of Santa Ana Mountains (Figure 4-1). This area is delimited to the south by Highway 241 and Trabuco Canyon, to the north by Highway 91, to the east by Highway 15 and to the west by Highway 241. Most of this territory is under the jurisdiction of the Cleveland National Forest to the east and Irvine Ranch to the west.

During our survey we identified 161 point locations where Tecate cypress were recorded. These locations correspond to GPS waypoints taken at the beginning, middle, and end of every 100 m transect used during the census of Tecate trees, in at least one location within each refugium (area with reproductive adults that escaped the recent fires), or where we found isolated adults or a patch of seedlings (Figure 2-5). In order to reduce spatial dependency among these data points, we randomly selected one point per transect and one point per refugium if there were more than one. In addition, we only included points that were greater than 30 m apart, as this was the target resolution intended for our model predictions. At the end of this selection process, we had 161 point locations for adults and 90 for seedlings.

We used MaxEnt 3.3.1 (Philips et al. 2006b) with 21 environmental variables that included topographic variables (elevation, slope, aspect), environmental variables (multiyear minimum and maximum of average temperatures and total precipitation, see below), soil characteristics (pH, % sand, % clay, % organic matter, absolute water content, and depth to any restrictive layer for root penetration), and vegetation information (vegetation type, dominant functional group, vegetation coverage, and average vegetation height). Table 4-1 describes the variables and the sources of digital layers used to calculate the variables. Layers for each variable were downloaded from LANDFIRE (2007), the Soil Survey geographic database (SSURGO 2009), and Climate Source Inc (2009). Topographic and vegetation raster layers from LANDFIRE had a spatial resolution of 30 m x 30 m; temperature and precipitation from Climate Source Inc. have approx 400 m x 400 m resolution and SSURGO maps had scales that varied from 1:12000 to 1:63360, which roughly gives a resolution of 32 x 32 m. Table 4-2 summarizes the averages of environmental attributes at the point locations used in the model.

For each variable we created a raster layer using a pixel size of 30 x 30 m. This would be the resolution of our model predictions. Data manipulation was minimal from layers provided by LANDFIRE (Table 4-1). Values of vegetation coverage and average vegetation height from LANDFIRE are reported as a range of values. Instead of using this range of values, we assigned a value to each cell that corresponds with the midpoint value of its range. Appendix Tables A1-A4 contain a detailed description of the codes used for these variables.

We derived seven different environmental variables from overall monthly temperature and precipitation layers, averaged from 1971 to 2002, provided by Climatic Data Source Inc. We grouped these monthly layers into growing season layers (October to March) and non-growing season layers (April to September). Subsequently for each cell, we estimated minimum and maximum temperature and precipitation values during growing and non-growing season months. In addition, we calculated average temperature and total precipitation during these two periods.

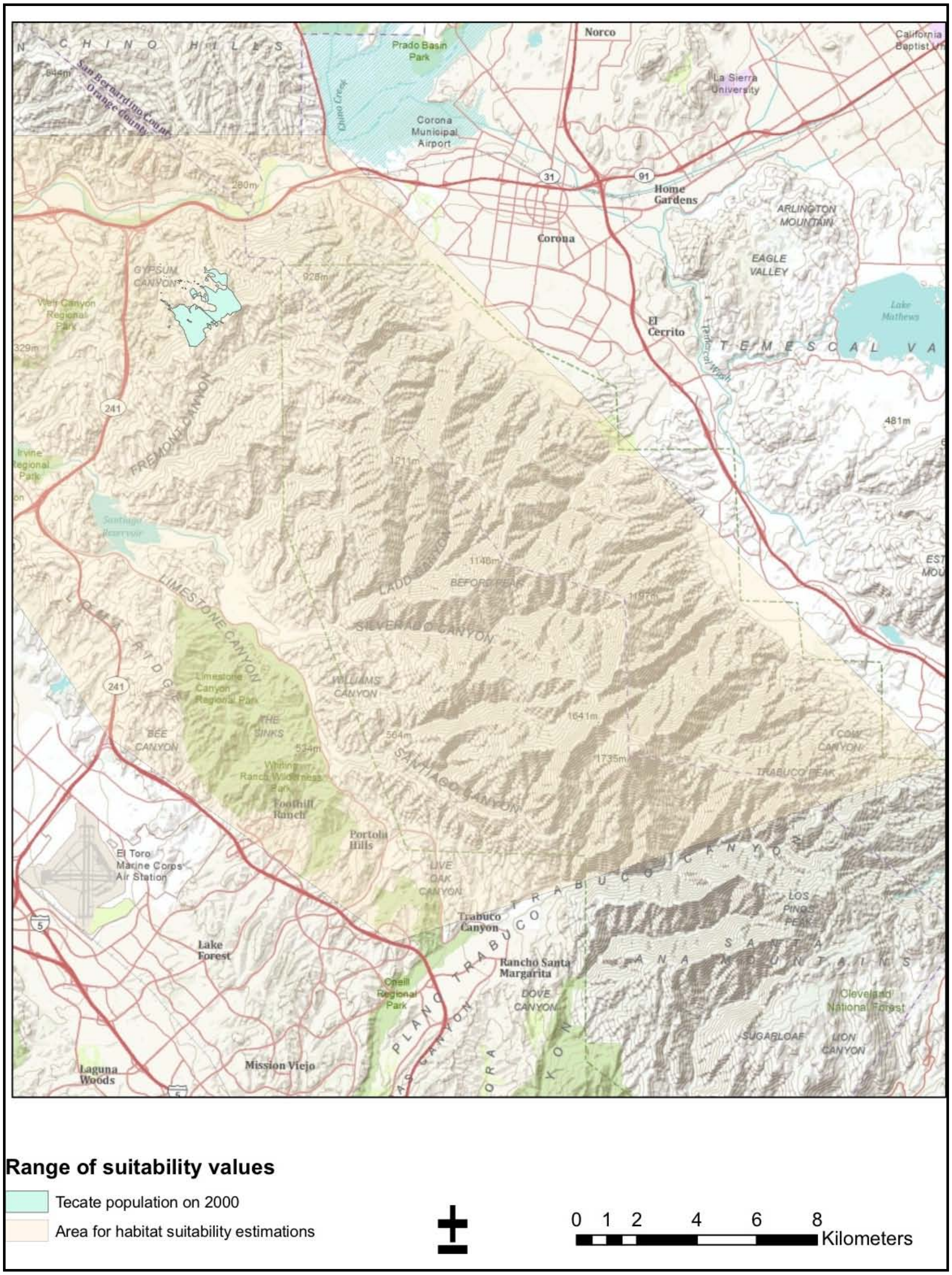

Figure 4-1. Current distribution of northern Santa Ana Mountains Tecate cypress and area used for habitat suitability predictions. This area is bordered to the south by Highway 241 and Trabuco Canyon, to the north by Highway 91, to the east by Highway 15 and to the west by Highway 241. North/south directions are indicated by ±; north corresponds to the top of the cross. Study area is located in the USGS Black Star Canyon 7.5 minute quadrangle.

Table 4-1. Environmental variables used in habitat modeling. Variables are grouped by type and source with a brief explanation of each variable. Detailed description codes used for vegetation variables are provided in Appendix A.

Type	Variable Name	Description	Source	Further manipulation
Topography	Elevation (m.a.s.l)	Altitude in meters above sea level	LANDFIRE	None
	Aspect	Azimuth in degrees of slope surface	LANDFIRE	Calculated from Elevation
	Slope	Percentage change of elevation over a specific area	LANDFIRE	Calculated from Elevation
Climate	Temperature during the growing season (ºC)	Multiyear average of monthly temperature from 1971 to 2000 in tenths of degree Celsius	CLIMATE SOURCE Inc. Interpolation using PRISM; Parameter-Elevation Regressions on Independent Slopes Model by PRISM group (www.prism.oregonstate.edu)	Average, maximum and minimum temperatures from October toMarch
	Temperature during non-growing season (ºC)			Average, maximum and minimum temperatures from April to September
	Precipitation during the growing season (mm)	Multiyear average of total monthly precipitation from 1971 to 2000		Total, maximum and minimum temperatures from October to March
	Precipitation during non-growing season months (mm)			Total, maximum and minimum temperatures from April to September
Soils	pH	Acidity measured with the 1:1 water method	SSURGO	
	% Sand		SSURGO	
	% Clay		SSURGO	
	% Organic Matter		SSURGO	
	Available water capacity (cm^3 water/ cm^3 soil)	Quantity of water that can be held by a given volume of soil	SSURGO	
	Depth to any restrictive layer (cm)	A layer is restrictive when it significantly impedes the movement of water and restricts root penetration. Soil without recorded restrictive layers are more .than 200 cm depth.	SSURGO	
Vegetation	Vegetation type	Categorical variable that identifies dominant species	LANDFIRE. Classification corresponds to the terrestrial system classification for the Western Hemisphere generated by NatureServe (www.natureserve.org/publications/usEcologicalsystems.jsp)	None
	Dominant functional group	Categorical variable indicating dominance of herbs, shrubs & trees	LANDFIRE	Derived from Vegetation coverage
	Vegetation height	Average height of the dominant vegetation based on existing vegetation type assignment	LANDFIRE. Values estimated using projections derived from digital orthophotographs and Landsat imagery between 1999-2003 (released in 2006).	We used the midpoint of reported intervals
	Vegetation coverage	Vegetation coverage estimated using percentages reported in discrete classes at 10 percent intervals, and separately for tree, shrubs & herbs		We used the midpoint of 10 percent intervals and eliminated the distinction between herb, shrubs, and trees

Table 4-2. Average (± standard deviation) environmental attributes at locations where Tecate cypress adults or seedlings are currently present.

Variable Name	Adult Locations	Seedling Locations
Elevation (m.a.s.l)	530.5 (±150.4)	566.9 (±108.3)
Aspect	SW (255 degrees)	SW (262 degrees)
Slope	15.7 (± 6.4)	14.9 (±4.8)
Temperature during the growing season (°C)	13.6 (±0.6)	13.6 (±1.0)
Temperature during non growing season months (°C)	20.1 (± 0.3)	20.1 (±2.2)
Precipitation during the growing season (mm)	371 (± 20.7)	415 (±12.0)
Precipitation during non-growing season months (mm)	70.8 (±4.8)	70.7 (± 3.4)
pH	6.4 (±0.7)	6.4 (±1.0)
% Sand	59.7 (±13.4)	60.4 (±12.3)
% Clay	15.9 (± 6.1)	15.7 (± 5.8)
% Organic matter	0.8 (±0.2)	0. 8 (±0.1)
Available water capacity(cm^3 water/ cm^3 soil)	0.14 (± 0.01)	0.14 (±0.01)
Depth to any restrictive layer (cm)	35.3 (±33.2)	29.3 (±24.9)
Vegetation type	Primarily California Marine Chaparral	
% Vegetation coverage	30.3 (±18.4)	21.8 (±14.4)

Soil information from SSURGO came separated by County and required more manipulation. We used Soil Data Viewer (USDA NRCS 2006) to generate thematic maps for each soil attribute. Given that the study area comprises territories within Orange, San Bernardino, and Riverside counties, we created three different thematic maps. Spatial information in SSURGO is organized in single map units that encompass information from at least three soil components. Each component includes information on six soil horizons. To obtain a single attribute value for each map unit, we used a weighted average. To obtain our weighted average, we first calculated the average attribute value of each component and then we calculated a weighted average per map unit using the percentage of each component as a weight. We used information from all six horizons. The resulting thematic maps were then converted to raster layers. We merged these three raster layers using the average value for those cells when there was data from more than one County for that cell. The area of overlap was minimal among the three county maps and limited to cells at county borders and constituted only 0.2% of cells.

Model Development

In order to characterize the importance of each variable we first parameterized a full model that included all topographic, environmental, soil and vegetation variables. We also parameterized three reduced versions of this model by excluding variables that were highly correlated. Table 4-3 summarizes variables that were highly correlated (correlation coefficient greater than 0.7); a full correlation matrix is presented in Appendix Table A5. In order to evaluate the predictive power of each group of variables, we also parameterized models that only contained the specific group of variables. Table 4-4 presents the different models used during the analysis.

Table 4-3. Correlation coefficients for highly correlated variables. Complete correlation matrix is provided in Appendix Table A.5.

Pair of variables	Correlation coefficient
Available water content-Depth to any restrictive layer	-0.738
%Clay-%Sand	-0.771
Elevation-Average non-growing season temperature	-0.796
Elevation-Minimum non-growing season temperature	-0.931
Elevation-Total growing season precipitation	0.910
Elevation-Total non-growing season precipitation	0.870
Functional vegetation group-Vegetation coverage	-0.710
Functional vegetation group-Vegetation height	-0.739
Functional vegetation group-Canopy height	0.761
Average non-growing season temperature-Maximum growing season temperature	-0.701
Average non-growing season temperature-Minimum growing season temperature	0.965
Minimum non-growing season temperature-Total non-growing season precipitation	0.920
Minimum non-growing season temperature-Total growing season precipitation	0.943
Total growing season precipitation-Total non-growing season precipitation	0.908

Table 4-4. MaxEnt models constructed for Tecate cypress in the Santa Ana Mountains. The following models were constructed using locations where adult Tecate cypress had been recorded in the past 27 years and current seedling locations.

Model	Variables Excluded
Full	None
Reduced 1	Depth to any restrictive layer % Clay Average non-growing and growing season temperature Minimum non-growing season temperature Maximum growing season temperature Total non-growing season precipitation
Reduced 2	Available water content %Sand Minimum and maximum growing season and non-growing season temperature Total non-growing season precipitation
Reduced 3	Available water content, %Clay, Average growing and non-growing season temperatures; total nongrowing season precipitation
Topography	All except Slope, Aspect, and Elevation
Climate 1	All except minimum growing season temperature, maximum non-growing season temperature, total growing season precipitation
Climate 2	All except average growing and non-growing season temperatures, and total growing season precipitation
Soil Full	Includes all soil characteristics
Soil Reduced	All except depth to any restrictive layer, % sand, % organic matter, pH
Vegetation	Includes all vegetation characteristics

We ran MaxEnt separately based on presence of adults or of seedlings. All runs used the default parameters except for number of iterations (set to 1000), random seed (set to true), random set (set to 30%), replicate run type (set to subsample) and replicates (set to 10). For every run, the program randomly partitioned the locations 10 times leaving 30% of the locations for testing the model. The default regularization multiplier is 1, and the threshold value is 0.00001. We used the auto feature setting, which allows the program to select the functional form of each variable. Variables can be included as linear, quadratic, product, hinge and threshold features.

Model Evaluation

Model evaluation and model comparisons were performed using the Area Under the Curve (AUC) values from the Receiver Operating Characteristic curve (ROC; Fielding and Bell 1997).
The ROC curve plots sensitivity and fractional predicted area, which is the proportion of all locations with predicted presence of the species. Sensitivity is defined as the proportion of the location with the species for which the model predicted the presence of the species (true positives). AUC is used to analyze model performance with respect to random (AUC=0.5), and it is a good metric for model comparisons (Fielding and Bell 1997). Values close to one indicate perfect performance of the classification algorithm. In terms of habitat models, a value of one indicates better predictive power and is interpreted as the probability of correctly classifying a random pair of occupied and unoccupied locations (Elith et al. 2006). MaxEnt also provides a test for the accuracy of model predictions using a binomial probability test on the set of test locations. In addition, MaxEnt provides percentage estimation of the importance of each variable during the parameterization process and an estimation of how much information each variable contributes to the model. This last estimation is accomplished through jackknife gain and loss values. These values represent the gain on model fit associated with each variable in isolation, and the loss when the variable is excluded from the model. We used both measurements to assess the importance of each variable in predicting the Tecate cypress distribution.

<u>Results</u>

All our habitat predictive models estimate high habitat suitability values in areas where Tecate cypress is currently present and in a very small proportion of locations where it is currently absent. Thus, models showed high predictive power but very low transferability, which is simply the potential for the model to be used in areas where species has not been recorded.

Models Constructed with Adult Locations

The full model has the highest average predictive power of all tested models (AUC=0.992) and the highest gain values on tested locations (Table 4-5). Figures 4-2 and 4-3 illustrate the range of habitat suitability values around adult locations in the Santa Ana Mountains. Areas with the highest habitat suitability values are located in the central portion of the current Tecate cypress distribution. Areas east and west of current Tecate locations have estimated suitability values above 0.75. The other locations where adult Tecates are currently present include the northeastern slopes of both Gypsum and Coal Canyons and areas were Tecate cypress were recently planted along the road in Cleveland National Forest. These areas have suitability values of less than 0.75. In areas surrounding current Tecate cypress locations habitat suitability falls between 0.1-0.5. Suitability drops near zero at extreme low and extreme high elevations to the east, west and south of the main Tecate cypress stand. These areas have low (minimum = 92 mm) or high precipitation during the growing season

Table 4-5. Results of MaxEnt models constructed with current adult Tecate cypress locations. Values indicate percent contribution of each variable during model training. Shaded cells highlight variables with high overall contribution to model training. Values in bold mark variables with highest test gain, and underlined values correspond to variables with the highest loss during jackknife simulations. Refer to Table 4-4 for model descriptions.

Variable type	**Variables/Model (see Table 4-1)**	**Full**	**Reduced 1**	**Reduced 2**	**Reduced 3**	**Topography**	**Climate 1**	**Climate 2**	**Soil Full**	**Soil Reduced**	**Vegetation**
Topography	Aspect	6.2	5.9	6.4	6.5	27.1					
	Elevation	1.4	2.7	2.7	2.7	**<u>48.8</u>**					
	Slope	2.6	2.8	3.6	3.3	24.1					
Climate	Average growing season temperature	13.5	-	<u>26.4</u>	-	-	-	42.4	-	-	-
	Average non-growing season temperature	2.1	-	3.6	-	-	-	15	-	-	-
	Maximum growing season Temperature	6.7	-	-	-	-	-	-	-	-	-
	Maximum non-growing season temperature	1.6	5.3	-	4.7	-	22	-	-	-	-
	Minimum growing season temperature	6.4	<u>24.7</u>	-	<u>22.4</u>	-	<u>39</u>	-	-	-	-
	Minimum non-growing season temperature	0.8	-	-	-	-	-	-	-	-	-
	Total growing season precipitation	10.7	14.8	**15.7**	13.7	-	**39**	**<u>42.2</u>**	-	-	-
	Total non-growing season precipitation	<u>7.7</u>	-	-	-	-	-	-	-	-	-
Soils	% Clay	0.5	-	2.3		-	-	-	1.8		-
	% Organic matter	5.3	8.2	8.3	5.7	-	-	-	18.7	21.2	-
	% Sand	**8.8**	**19.8**		**11.4**	-	-	-	**<u>27.1</u>**	**<u>30.2</u>**	-
	Available water content	0.3	0.2			-	-	-	5.1		-
	Depth to any restrictive layer	12.1	-	15.6	15.3	-	-	-	42.2	43.1	-
	pH	0.6	2	2.4	1.1	-	-	-	5	5.5	-
Vegetation	% Vegetation coverage	8.5	7.2	8.6	8.5	-	-	-	-	-	**<u>68.8</u>**
	Vegetation type	4.2	6.3	3.8	4.7	-	-	-	-	-	31.2
	Vegetation-functional group	0.1	0.1	0.2	1	-	-	-	-	-	-
Average Training AUC		**0.9922**	**0.979**	**0.978**	**0.976**	**0.896**	**0.972**	**0.964**	**0.922**	**0.923**	**0.842**
Range Test Gain		**3.9919-4.3945**	**3.2567-3.7628**	**3.3011-3.9604**	**3.2939-3.7244**	**1.2314-1.8201**	**2.845-3.2106**	**2.9769-3.5298**	**1.4404-1.8817**	**1.4629-2.0229**	**0.8272-1.3755**

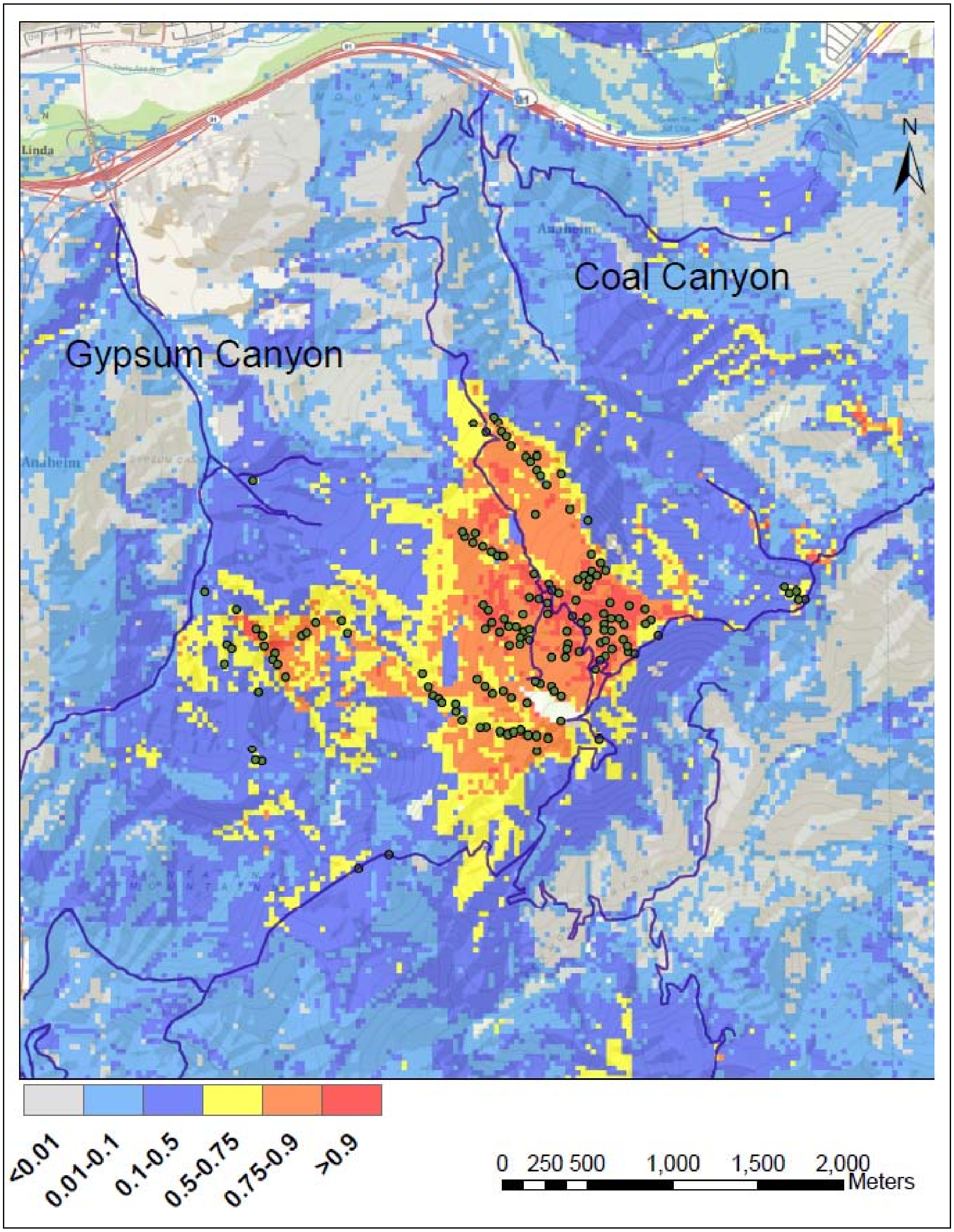

Figure 4-2. Habitat suitability predictions for adult Tecate cypress in areas where they are currently present in the northern Santa Ana Mountains. MaxEnt was used to estimate habitat suitability based upon adult point locations (green circles). MaxEnt output was reclassified into six categories, each illustrated with a different color on the map; warmer colors indicate higher habitat suitability values. Study area is located in the USGS Black Star Canyon 7.5 minute quadrangle.

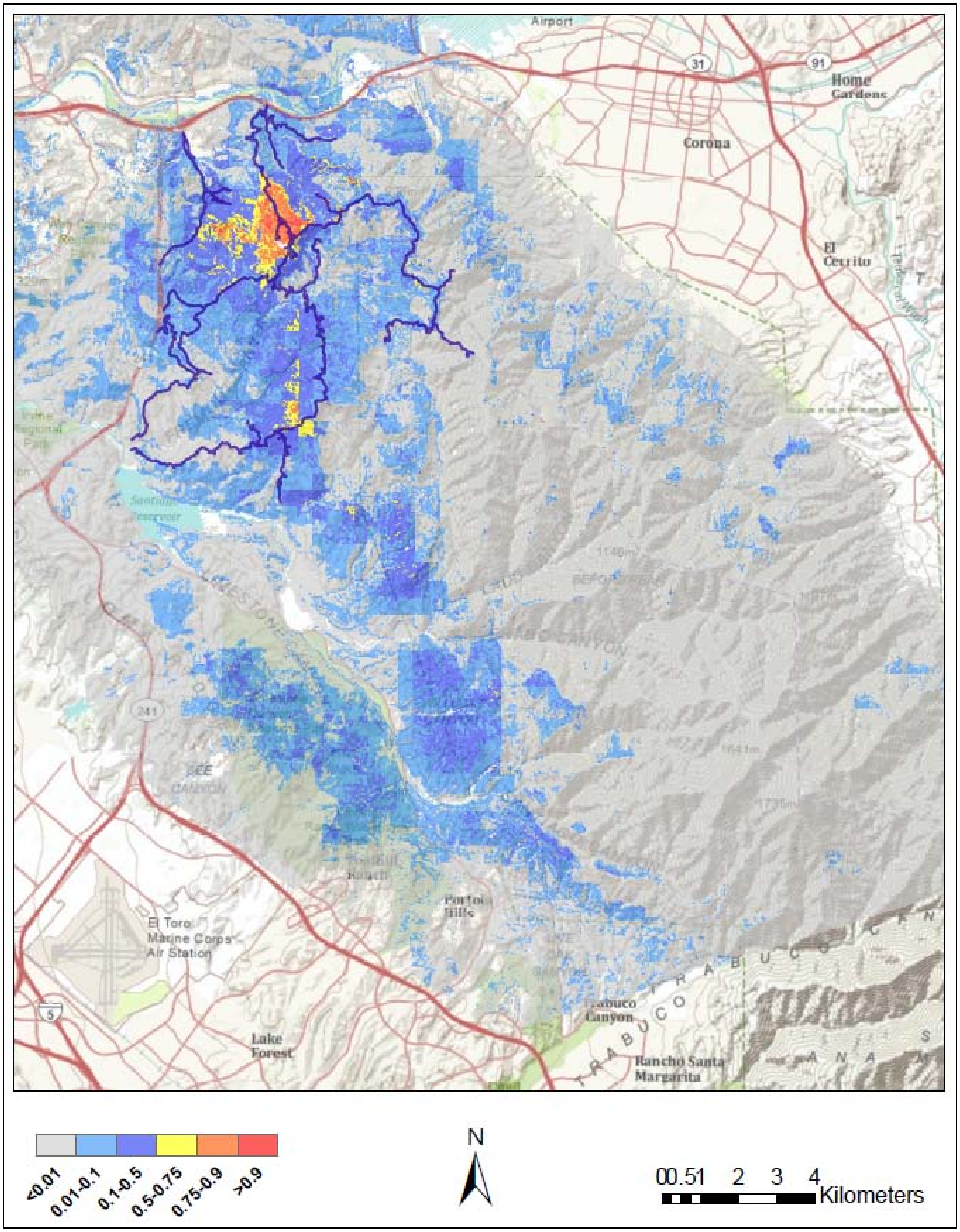

Figure 4-3. Habitat suitability predictions for adult Tecate cypress in the Santa Ana Mountains. MaxEnt was used to estimate habitat suitability based upon adult point locations (green circles). MaxEnt output was reclassified into six categories, each illustrated with a different color on the map; warmer colors indicate higher habitat suitability values. Study area is located in the USGS Black Star Canyon 7.5 minute quadrangle.

(maximum = 1733 mm), low annual average temperatures (less than 13.5°C) and/or soil with the restrictive layer deeper than 14 cm.

The variables with the highest contribution to the model are related to environmental conditions and soil physical properties (Table 4-5). In decreasing order of importance, these variables are: average growing season temperature, depth to any restrictive layer, total growing season precipitation, and percent sand. The importance of these variables is also evident from the jackknife tests. During the model fitting, percent sand, percent clay and all climate variables showed high gain values when modeled in isolation. Conversely, none of the variables showed a significant loss value when removed from the model, which implies that none provided unique information during model fitting. Response variable curves indicate that habitat suitability is lower at high temperatures, in very shallow or very deep soils, in drier areas, or in soils with low percent sand. Specifically, habitat suitability decreases drastically when average growing season temperatures are above 13.5°C, depth to any restrictive layer is greater than 14 cm, precipitation during the growing season is above 400 mm and percent sand is below 50%.

Reduced models consistently performed similar to the full model implying that the correlation among variables had little effect in identifying which variables are most important. Models with only climate variables and soil attributes performed best among the reduced models (Table 4-5). In addition, when only climate variables are included in the models, both predictive power and range on test gain values are close to those values achieved with the full model.

Despite this agreement based on performance measurements, reduced models differed substantially in predicting the extent of high suitablity areas (Figure 4-4). In general, models assign suitability values greater than 0.5 to areas at intermediate elevations on the northwest flank of the Santa Ana Mountains. In particular, the topographic model estimates habitat suitability higher than 0.75 in several scattered locations at intermediate elevations along northeast and northwest slopes of the Santa Ana Mountains (Figure 4-4; upper left panel). Some of these locations are strongly associated with drainage features. In contrast, models with only climate variables (Figure 4-4; upper right panel) and only soil variables (Figure 4-4, lower left panel) predict more restrictive distributions of suitable habitat. Soil models associate habitat suitability values between 0.5 and 0.75 with areas characterized by 50% rock outcrops and 40% soils within the Cieneba complex. These soils are derived from granite, are shallow (10-50 cm), have an average of 67.4% sand, 12.4% clay and have a low organic matter content at the surface horizon (less than 1%; SSURGO, 2009). Finally, the model with only vegetation variables predicts two areas with high suitability values (Figure 4-4; lower right panel). One area corresponds with the current distribution of Tecate cypress and the other with intermediate elevations along the Harding, Silverado, and Santiago Canyons. These areas have vegetation coverage lower than 35%. Except for areas where Tecate is currently present, there is little overlap among areas with habitat suitability values greater than 0.5 among all models. This result in part explains the overall restrictive distribution of suitable habitats when using the full model.

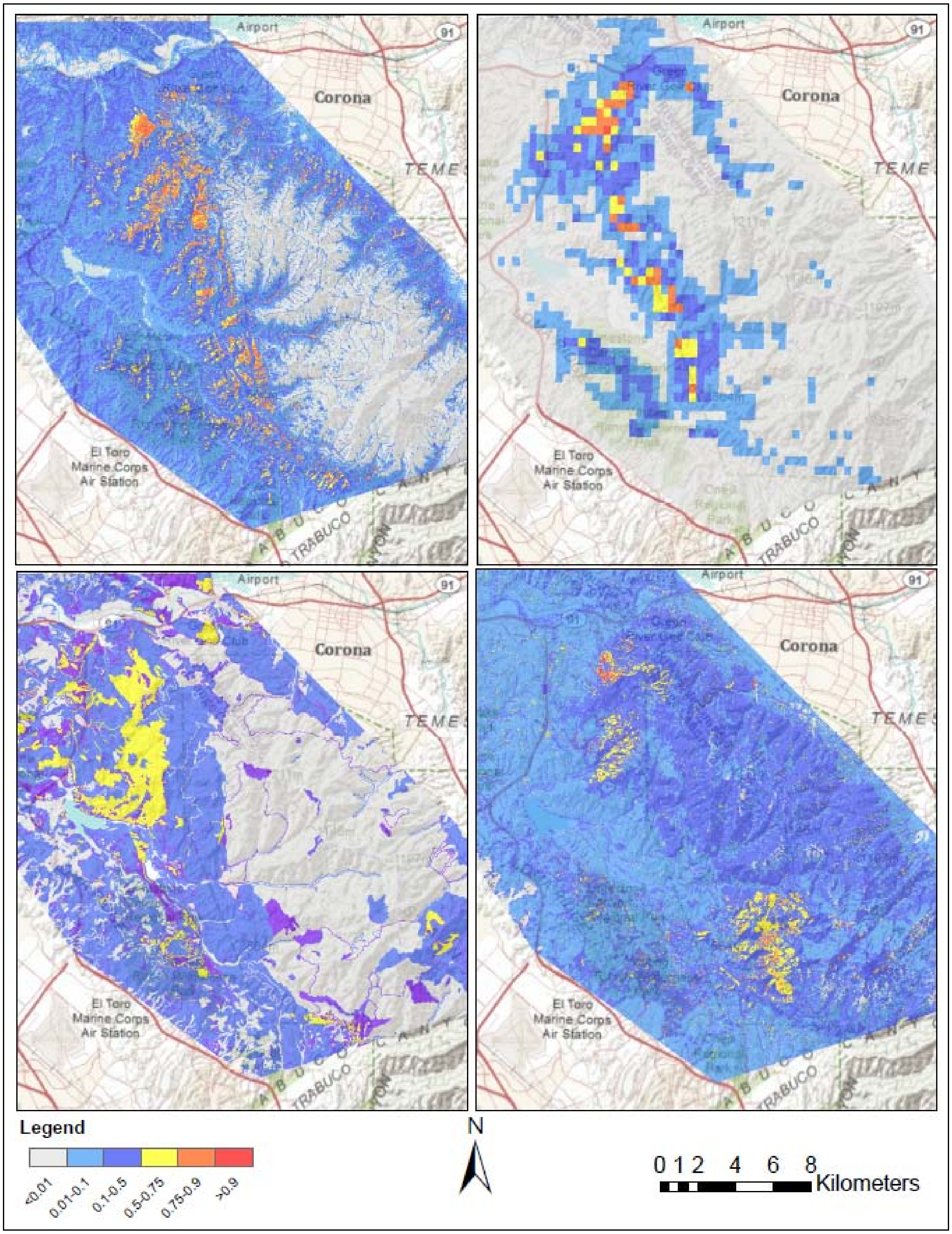

Figure 4-4. Reduced model predictions for adult Tecate cypress habitat suitability in the Santa Ana Mountains. To estimate the importance of each type of variable, models were constructed with subsets of available variables. Models were run with only topographic variables (upper left panel), only climate variables (upper right panel), only soil characteristics (lower left panel) and only vegetation attributes (lower right panel). Warmer colors indicate higher habitat suitability values. Study area is located in the USGS Black Star Canyon 7.5 minute quadrangle.

Models Constructed with Seedling Locations

Similar to the models constructed with adult locations, habitat models constructed with seedling locations show high predictive power but restrictive suitability predictions. The full model AUC was 0.996 with a gain range on test data of 4.392-4.818 (Table 4-6). In general, the seedling models estimate even less suitable habitat for Tecate cypress than the adult models. Those areas with habitat suitability values greater than 0.9 are located southeast of the current seedling distribution (Figures 4-5 and 4-6). All other locations within the main population have habitat suitability values between 0.75 and 0.9. Locations with suitability values between 0.5 and 0.75 are at the extreme of the distribution along the lower Gypsum Canyon, at lower elevations on the slope facing Coal Canyon and in the Fremont Canyon stand. Areas surrounding current seedling locations have habitat suitability values between 0.1-0.5. With the exception of two locations, habitat suitability is near zero in areas further from current Tecate cypress locations. Habitat suitability values at the two locations distant from current stands are along the western slope of Coal Canyon and close to the intersection of Green River Road and Highway 91.

Variables with the highest contribution to the model were vegetation coverage and soil depth to any restrictive layer (Table 4-6). In addition to these variables, total precipitation during the growing season showed high gain values during the jackknife evaluations. No variable except for vegetation coverage showed high loss during the model parameterization, indicating a generalized lack of variable-specific information.

Response variable curves indicate that habitat suitability decreases with vegetation coverage, reaching values below 0.6 at around 40% coverage. Suitability also decreased steadily with depth to any restrictive layer, dropping to values below 0.5 at depths greater than 80 cm. Habitat suitability increased strongly with precipitation during the growing season, although it reaches a plateau at around 400 mm. In general, areas with habitat suitability values higher than 0.5 have restrictive layer depths lower than 71 cm, intermediate precipitation during the growing season and low percent vegetation cover (less than 30%).

Although models with only one type of variable perform similarly to full models, they show strong differences in the estimation of habitat suitability (Tabe 4-6 and Figure 4-7). In agreement with models based on adult locations, topographic and vegetation models using seedlings locations identified more suitable habitat, whereas the climate model found suitability restricted to current Tecate cypress locations. The soil model associated suitable habitats with a soil type characterized by a high proportion of rock outcrops within the Cieneba complex only, similar to the model based on adult locations.

Table 4-6. MaxEnt results for models constructed with current Tecate cypress seedling locations. Values indicate the percentage contribution of each variable during model training. Values in bold mark variables with the highest test gain, and underlined values correspond to variables with the highest loss during jackknife simulations.

Model Type	Variables	Full	Reduced 1	Reduced 2	Reduced 3	Topography	Climate	Soil	Vegetation
Topography	Aspect	1.9	3.7	2.7	3.8	41.3			
	Elevation	1.4	9.9	1.9	2.3				
	Slope	2	4.4	4.8	3.1				
Climate	Average non-growing season temperature	0		1.3		34.1	0.8		
	Average growing season temperature	1.4		4.7		24.5	4.6		
	Maximum growing season temperature	2.6					26		
	Maximum non-growing season temperature	5.8	8.1		5.8		15		
	Minimum growing season temperature	2.8	14.4		3.6		8.6		
	Minimum non-growing season temperature	0.2					8		
	Total growing season precipitation	2.9	5.8	7.1	4.5		20.5		
	Total non-growing season precipitation	3.2					16.5		
Soils	Available water content	0.2	1					1.3	
	Depth to any restrictive layer	30.2		30.6	28.9			72.2	
	pH	2	7.4	2.6	2.2			5.3	
	% Clay	0.2	0.3	0.2				2.3	
	% Organic matter	2.3		3.3	2			12.7	
	% Sand	1.7	1.1	2.1	1.7			6.1	
Vegetation	Functional group	0.3	0	0	0.4				
	Vegetation coverage	31.6	37.4	36.4	33.2				70.3
	Average vegetation height	2.5	2	2.2	2.7				10.6
	Vegetation type	4.8	0.3	0.3	6				19.1
Average Training AUC		**0.996**	**0.994**	**0.993**	**0.994**	**0.932**	**0.993**	**0.961**	**0.941**
Range Test AUC		**4.392-4.8148**	**4.3128-4.9785**	**4.08-4.593**	**4.0896-4.4884**	**1.5656-2.4263**	**3.9218-4.8946**	**1.9575-2.4915**	**3.6439-4.1742**

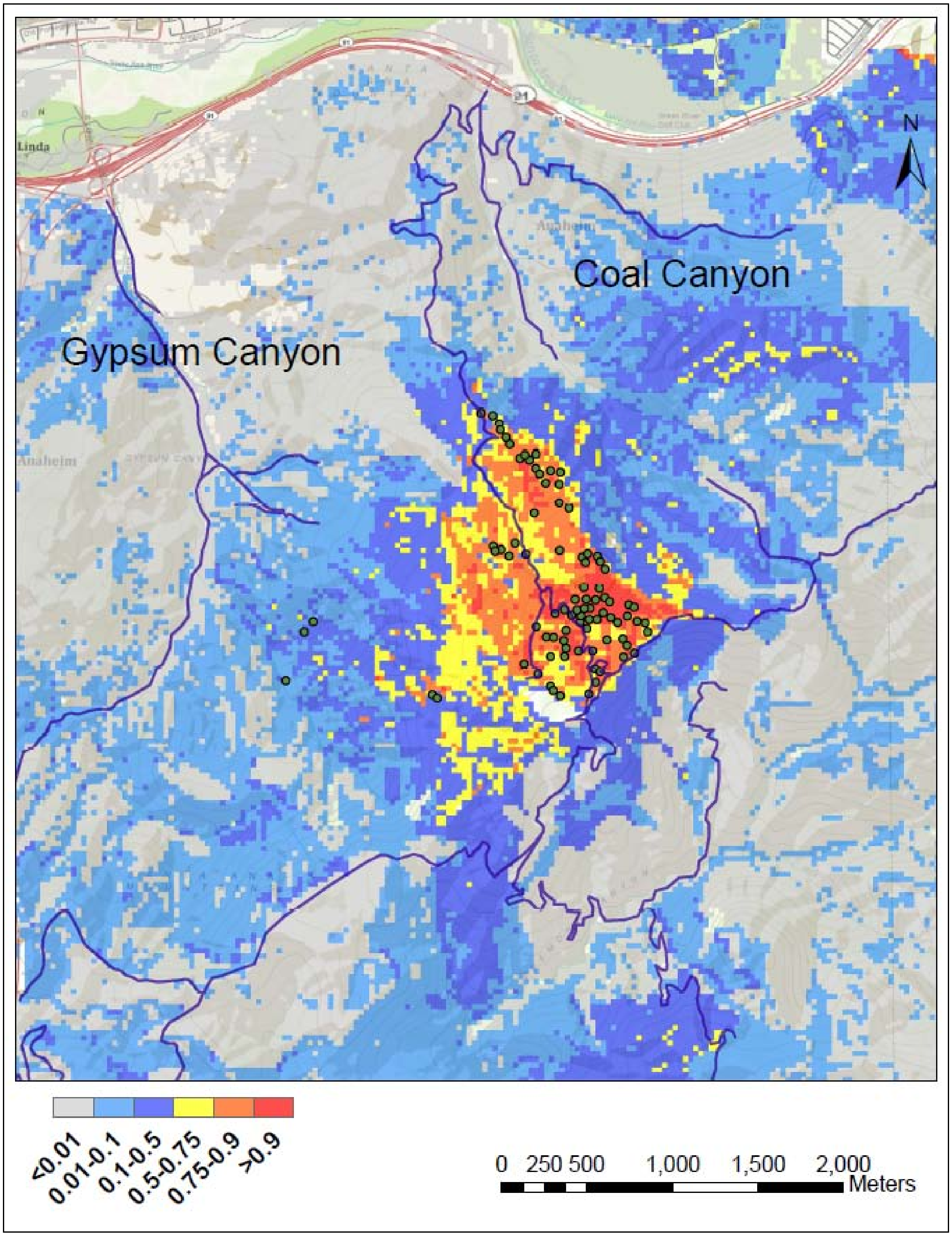

Figure 4-5. Habitat suitability predictions for seedling Tecate cypress in areas where they are currently present in the northern Santa Ana Mountains. MaxEnt was used to estimate habitat suitability based upon seedling point locations (green circles). MaxEnt output was reclassified into six categories, each illustrated with a different color on the map; warmer colors indicate higher habitat suitability values. Study area is located in the USGS Black Star Canyon 7.5 minute quadrangle.

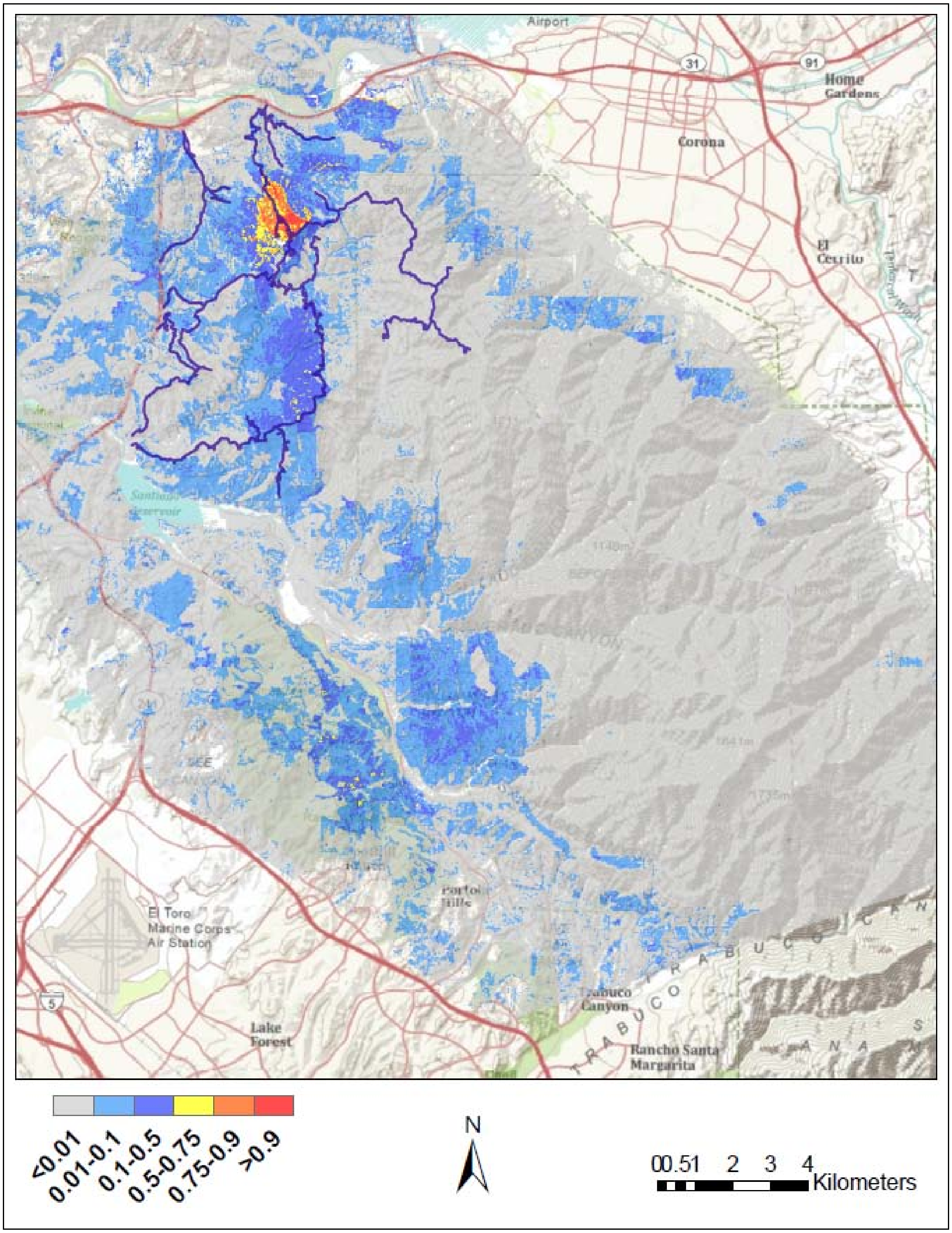

Figure 4-6. Habitat suitability predictions for seedling Tecate cypress in the Santa Ana Mountains. MaxEnt was used to estimate habitat suitability based upon seedling point locations (green circles). MaxEnt output was reclassified into six categories, each illustrated with a different color on the map; warmer colors indicate higher habitat suitability values. Study area is located in the USGS Black Star Canyon 7.5 minute quadrangle.

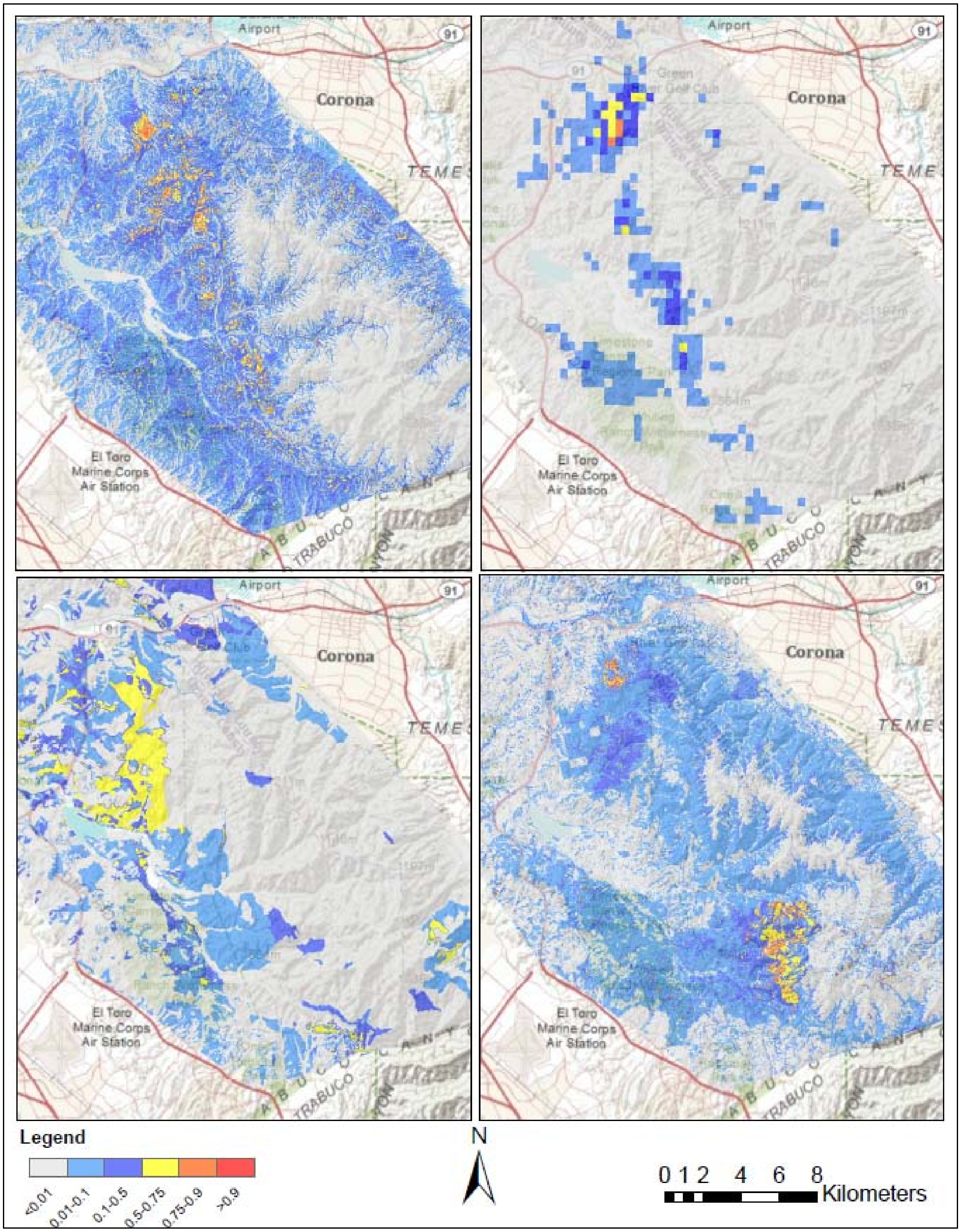

Figure 4-7. Reduced model predictions for seedling Tecate cypress habitat suitability in the Santa Ana Mountains. To estimate the importance of each type of variable, models were constructed with subsets of available variables. Models were run with only topographic variables (upper left panel), only climate variables (upper right panel), only soil characteristics (lower left panel) and only vegetation attributes (lower right panel). Warmer colors indicate higher habitat suitability values. Study area is located in the USGS Black Star Canyon 7.5 minute quadrangle.

Identifying Priority Tecate Cypress Restoration Areas in the Santa Ana Mountains

Suitable areas for restoration were determined by combining the results from the full habitat suitability model for seedlings (areas with suitability > 0.5; Figure 4-6) and burn probabilities under Santa Ana Wind conditions in Section 3 (burn probability of <0.5; Figure 3-9). Suitable areas are located primarily in the Coal Canyon Ecological Reserve within the current extent of the Tecate cypress population (Figures 4-8 and 4-9). These results are driven by higher suitability indices associated with areas where seedlings are currently growing. We consider that areas that currently have low seedling densities, but where Tecate cypress have been previously reported should hold the highest priority during restoration efforts. These areas include sections of the Coal Canyon Ecological Reserve with low seedling densities (Figure 2-4) and areas on Irvine Ranch Land, where recent fires have decimated Tecate seedlings. We have indicated in Figure 4-10 areas with low seedling densities in the Coal Canyon Ecological Reserve.

Discussion

The primary objective of this study was to identify areas suitable for Tecate cypress in the Santa Ana Mountains. For this purpose, we used a habitat modeling approach (MaxEnt) based on environmental relationships of the current Tecate cypress population in order to estimate habitat suitability outside the current extent of the population. Several environmental variables were correlated with current Tecate cypress locations. Models predicted low habitat suitability outside of the current Tecate cypress range. Although such a lack of transferability constrains our ability to identify suitable habitat at a fine-scale resolution, we can roughly classify the landscape into areas with greater suitability for Tecate cypress.

Priority restoration sites are identified in Figures 4-8 through 4-10. These are areas suitable for seedlings based on environmental relationships at locations where Tecate cypress currently occur and on low probability of burning during a fire in Santa Ana conditions. These areas are recommended for initial restoration efforts. Eventually, it would be desirable to identify additional restoration areas outside of the recent distribution of Tecate cypress in order to spread the population over a greater area and reduce the risk of the entire population burning in any single fire event. To identify these future restoration sites, several environmental variables are useful in guiding restoration site selection. Areas with habitat suitability values greater than 0.5 are predominately located on the northwest flank of the Santa Ana Mountains. These areas are at intermediate elevations, have mild average annual temperatures (less than 13.5°C) and moderate precipitation. Their soils are shallow (restrictive layer less than 14 cm deep) with a high percentage of sand (more than 50%) and low vegetation coverage (less than 30-40%). While small in size, several sites can be identified (see Figures 4-3 and 4-6) that are characterized by these environmental measures that are distant from the current main stand of Tecate cypress. These are candidate planting sites due to environmental suitability and the low likelihood of being burned at the same time as the main stand.

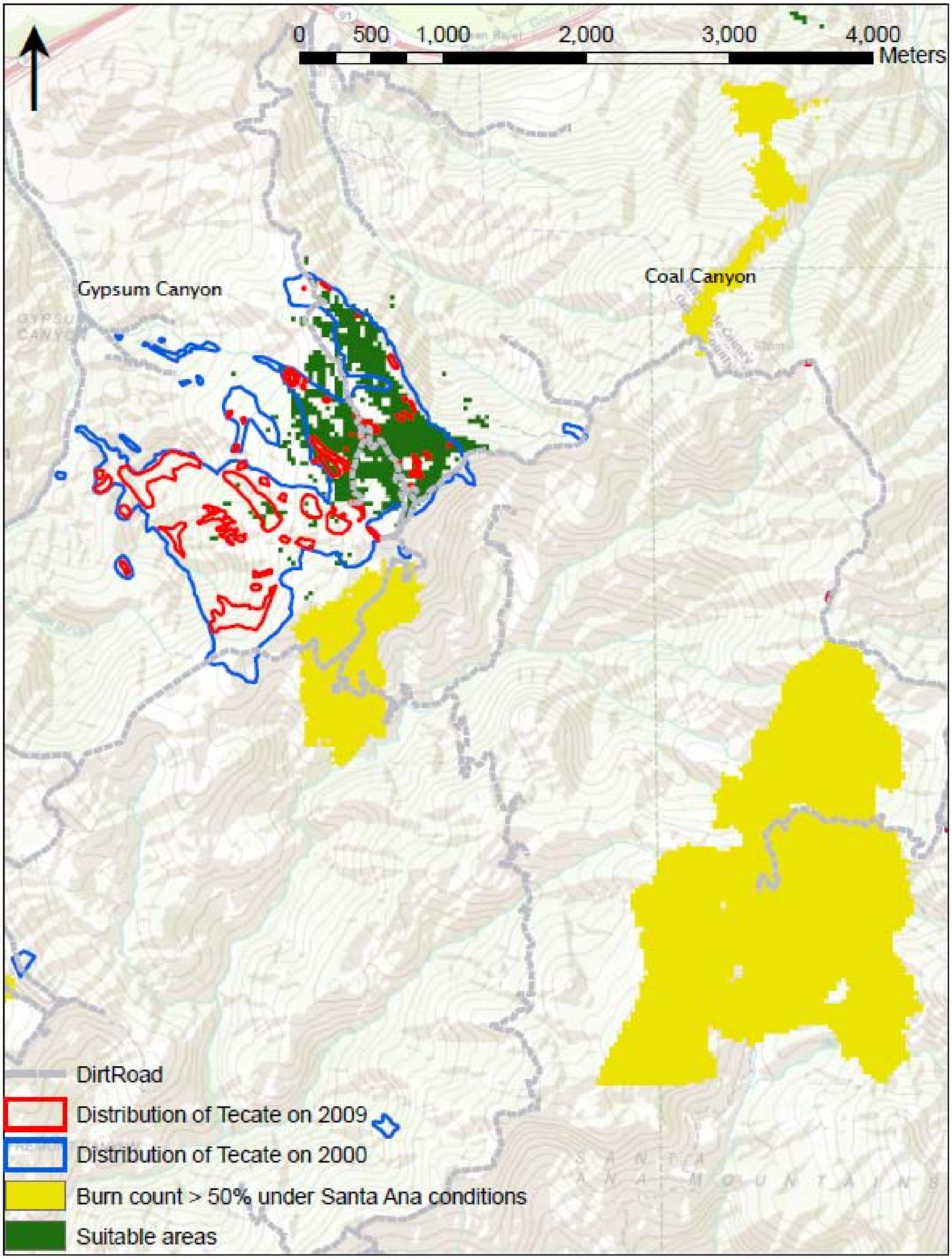

Figure 4-8. Suitable areas for restoration after combining fire burn probabilities and habitat suitability predictions. Suitable areas in green were estimated by selecting those areas with a predicted habitat suitability greater than 0.5 for seedlings (Figure 4-6) and a burn probability of less than 0.5 under Santa Ana Wind conditions (Figure 3-9). Study area is located in the USGS Black Star Canyon 7.5 minute quadrangle.

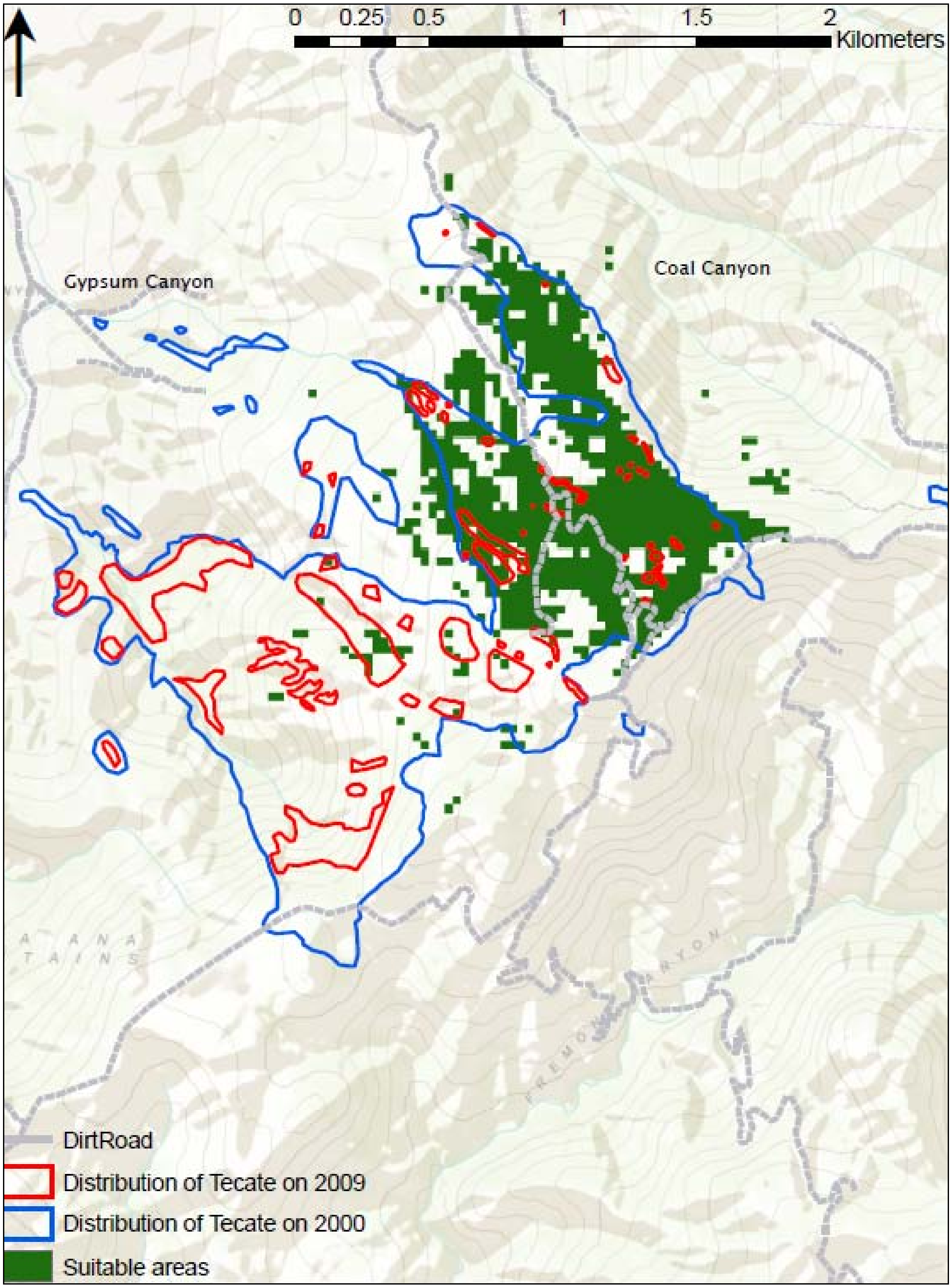

Figure 4-9. Close-up of suitable areas for restoration in comparison with areas previously occupied by Tecate cypress. Suitable areas for restoration were calculated by combining the results of habitat suitability and fire models. Results are driven by current distribution of seedlings as determined by 2009 surveys. Study area is located in the USGS Black Star Canyon 7.5 minute quadrangle.

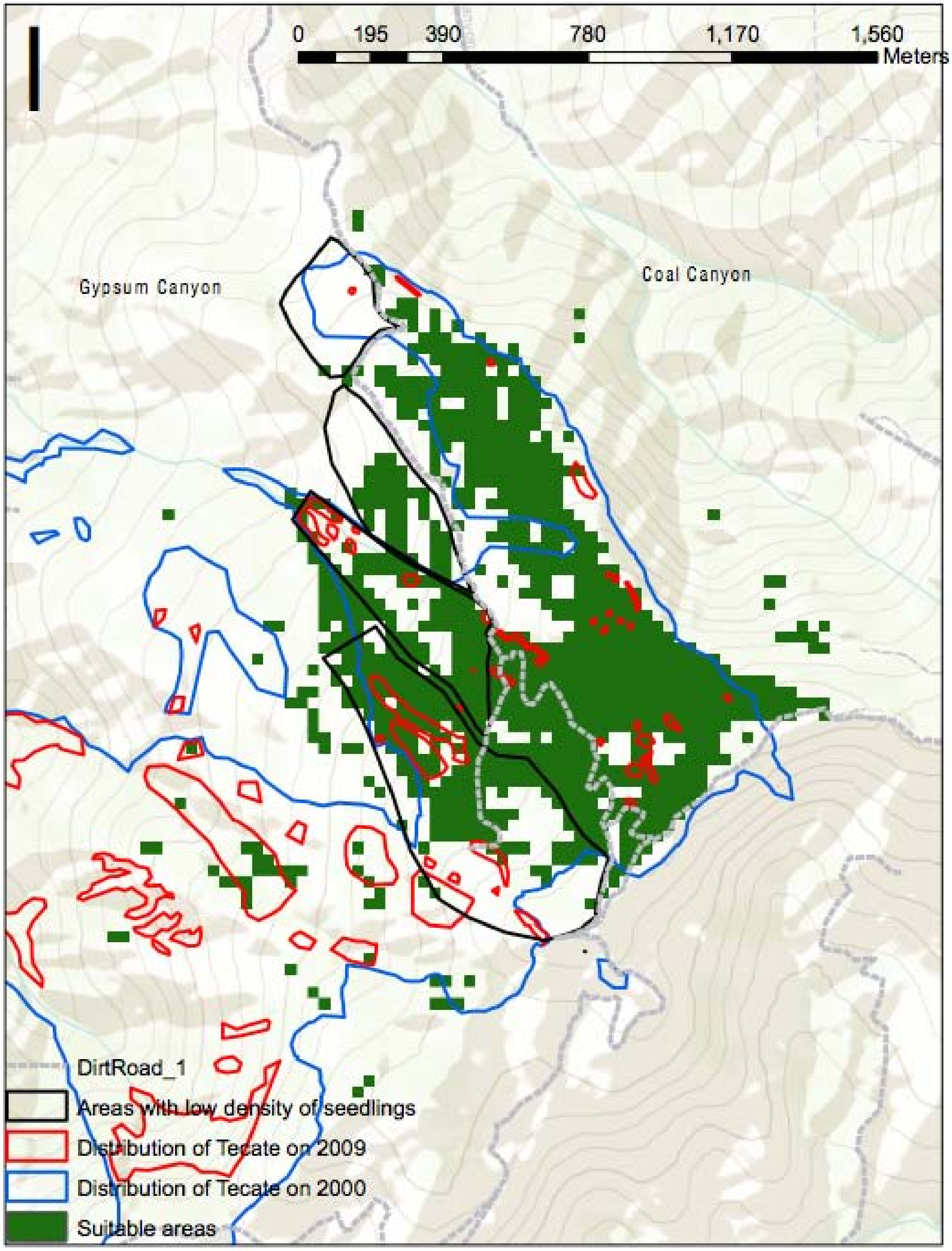

Figure 4-10 Suitable areas for restoration of Tecate cypress in the Coal Canyon Ecological Reserve. Suitable areas for restoration were determined by combining results from habitat suitability and fire models. Most areas coincided with the current distribution of seedlings documented during 2009 surveys, reflecting the fact the models were developed with these locations. Some suitable restoration areas are located in areas with low density of seedlings and should have the highest restoration priority. Study area is located in the USGS Black Star Canyon 7.5 minute quadrangle.

Models with only one type of variable also help to identify areas suitable for restoration. The difference in resolution between variables included in our full models constrains the predictability of these models. Nevertheless, models with the same type of variables with a consistent resolution will not have this problem. If a particular type of variable proved to be relevant in full models, then reduced models with only these variables could identify where Tecate cypress are likely to succeed. For this reason and under the circumstance that no further refinements of the models are possible, we recommend considering predictions from models with only one relevant type of variable. This will be particularly applicable in the selection of planting areas.

Important Caveats

While we have identified environmental variables that strongly relate to Tecate cypress presence, there are several caveats with these predictive habitat suitability maps. First, it is important to consider that the low proportion of suitable habitat identified by modeling is in part explained by the aggregated distribution of point locations in relation to the extent of the study area. At the resolution we used for soil and climate variables, this aggregation implies that the variability within these variables is limited. For example, although point locations fall within several soil types, most of the areas with Tecate are associated with just one soil unit. This association explains the generally large contribution of both soil and climate variables during model training, although it is unclear whether this soil type indeed limits the presence of Tecate cypress.

While we cannot avoid the fact that the Tecate cypress population in the Santa Ana Mountains is distributed over a small area, using locations that are aggregated in relation to the area where predictions are estimated is particularly problematic in MaxEnt (Peterson et al. 2007). It has been suggested that there is a tendency of the MaxEnt method to produce models with low transferability, which means that models poorly predict presence of a species in areas without information. When predictions imply interpolations in an otherwise well-sampled area, MaxEnt performs better than most other presence-only habitat modeling techniques (Elith et al. 2006). Nevertheless, when predictions are based on aggregated data MaxEnt tends to underestimate suitability in areas with recorded presence (i.e., to increase omission rates). In the absence of additional point locations, MaxEnt should be used with relaxed assumptions. One possible approach is to relax the thresholds used to declare presence/absence during the model evaluation (Phillips et al. 2006a), and to interpret the habitat suitability index in terms of presence/absence instead of as a continuous variable (Peterson 2006). Given that runs with relaxed threshold values yielded similar predictions, we restricted our discussion to contrast areas with habitat suitability values lower or higher than 0.5.

Second, it is important to consider that planted populations have been successful despite being in areas with low suitability predictions from our habitat models. The estimated suitability index is consistently low in planted locations, independent of the model type. Although the habitat suitability values may capture conditions that favor natural establishment, this result implies that environmental variables used in this model do not fully capture conditions that favor Tecate survival when planted. Tecate cypress can be considered a versatile species that can tolerate a variety of soil conditions. This characteristic will facilitate recovery strategies that depend upon ex-situ cultivations and subsequent re-introduction, even when these re-introductions are planned outside current Tecate locations. Thus, if projects were to develop that involve outplanting of Tecate seedlings, these projects may bypass some of the important "filters" identified in these habitat models. If most of the habitat restrictions identified by these models are due to low dispersal or strong environmental sensitivity in early germination, these restrictions would not apply to planting restoration projects. More research is needed to evaluate the success of small plantings along environmental gradients and determine habitat restrictions for restoration efforts.

Third, it is important to estimate the intensity with which Tecate have been sampled in the study area when assessing the validity of habitat models. Historical records of Tecate cypress in the Santa Ana Mountains consistently identify the current location of this species as the only location where this species can grow in this region. This restrictive distribution implies that the establishment of this species could be truly restricted to a particular area rather than a sampling bias of the models themselves. Under this circumstance, our recommendation would be to first address the nature of that restriction by including occurrence data from other parts of the species distribution or by increasing resolution in environmental variables.

The potential that Tecate cypress is restricted to a particular soil type is particularly intriguing and should be carefully evaluated. Several authors have suggested that the distribution of Tecate cypress in particular and cypress species in general, is restricted by soil characteristics (Wolf, 1948; McMillan 1956). Because almost all New World cypress species have been grown in a variety of soil types, their restriction to soils with particular characteristics is probably a consequence of several ecological factors, not just of a narrow physiological tolerance to specific soil properties. More detailed studies of soil characteristics at Tecate cypress stands support the argument that restricted distribution of Tecate cypress has more to do with competition with chaparral species than to a narrow physiological tolerance for a particular soil type (Stottlemeyer and Lathrop, 1981; Dunn 1986).

Although our models have consistently identified soil characteristics as relevant to predicting habitat suitability for seedlings, model comparisons suggest soil characteristics might not be highly relevant at the scale of our models. First, the weight of soil variables during modeling training is mostly driven by the aggregated nature of our modeling points. Second, when depth to a restrictive layer is not included in the model, vegetation coverage had the highest contribution during model training, followed by minimum growing season temperature (Table 4-6). This model achieved similar performance to the full model, suggesting that soil depth is not as important for predicting Tecate cypress seedling distribution as suggested by its percent contribution from the full model. In fact, the group-specific model with only soil characteristics shows lower performance values than the full model. In addition, soil characteristics are important for modeling adult habitat suitability but less important for seedling suitability, despite adult locations showing wider variability in soil characteristics. This could indicate that seedling recruitment is less limited by resource competition and more by suitable microsites. Thus, in order to fully evaluate Tecate cypress edaphic restrictions and test these ideas, planting trials over a range of soil characteristics would be appropriate.

Overall Recommendations

Our modeling efforts have identified priority areas for restoration based on seedling habitat suitability within the recent Tecate cypress distribution. We have also identified areas that may be most suitable for expanding the distribution of the Tecate cypress population in the future. In general these areas are at intermediate elevations mostly on northern slopes, with intermediate values of precipitation and temperature during the growing season, and on shallow soils with high percentage of sand, and low vegetation coverage. However, there are several important limitations to the model results due to the highly aggregated nature of the existing population. The utility or our modeling approach would be dramatically improved by several extensions to the project. First, a more extensive exploration of habitat characteristics would greatly increase our power to identify habitat suitability. Incorporating other areas with current Tecate populations, such as those in the Otay and Guatay mountains, Tecate peak in San Diego County, and where possible, scattered stands in Baja California, Mexico, would reduce the problems associated with data aggregation in this current project. It would be particularly useful to include soil attributes associated with these locations, and information on presence of other abundant native species such as *Salvia mellifera*, *Adenostoma fasciculatum*, and *Ceanothus* sp., which were the most abundant species in our study area.

Second, trial plantings would verify the important environmental limitations of the species. In particular, it would be useful to determine whether the environmental restrictions may be much less severe with planned plantings relative to natural recruitment. If so, the current habitat suitability models may substantially underestimate the suitable habitat for planted restoration projects.

5.0 THREATS TO TECATE CYPRESS POPULATION

The Tecate cypress population in the northern Santa Ana Mountains is threatened by a number of factors. Of particular concern is the fact that the population is fragmented and confined to a small distributional extent. Following is a brief description of the potential threats to Tecate cypress.

Fire

The most serious threat to the northern Santa Ana Mountains population of Tecate cypress is frequent, large wildfires. As discussed in Section 2, recent wildfires have resulted in a Tecate cypress population that is currently fragmented into small and isolated patches. Most refugia supporting adult trees capable of reproduction are located in areas with low probability for successful recruitment. Base on the fire risk assessment and population modeling (Section 3), if a fire burns through the population in the next 25-30 years this would be a serious threat to the persistence of this population in the northern Santa Ana Mountains. The analyses show that the Tecate cypress population is most sensitive to changes in seedbank size following a wildfire event and that it is important to connect future refugia to areas suitable for recruitment. Frequent and large wildfires put the population at risk when the majority of population is too young to achieve maximum seed production and ensure sufficient seed for replacement following a fire. The fire risk assessment and dynamic population analyses show that Tecate cypress population growth becomes negative with fire return intervals less than 35 years.

Since 1910 there has been a change in the frequency of fires in southern California shrublands, with the number of fires ignited positively correlated to population density (Keeley et al. 1999, Keeley and Fotheringham 2001). Fires are now more frequent in occurrence because of human caused ignitions and the rate of burning is greater than historically (Keeley and Zedler 2009). Orange County's ten largest recorded wildfires between 1914 and 2007 ranged from 14,339 to 68,104 acres (FRAP 2009). More than half a million acres burned in the County during this period with 25% of fires accounting for 89% of the land that burned. Five of the ten largest recorded wildfires occurred in the Central Reserve of the NCCP/HCP, the region where the Tecate cypress occurs. Over the last decade, several large Santa Ana wind-driven fires have burned through the larger Tecate cypress stands in Orange and San Diego Counties, making this species vulnerable to accelerated population decline and local extinction if fires burn through these populations in the next few decades.

Drought

Tecate cypress appears to be vulnerable to severe drought based upon observations of adult mortality and low levels of seedling recruitment. Southern California experienced substantial annual variability in precipitation over the last decade, with multiple years of drought. Between 1999 and 2008, there were six years of below average rainfall recorded at official weather stations in Tustin (1999-2003) and Irvine (2004-2008), several miles west of the Tecate cypress population (Table 5-1; Western Regional Climate Center 2009). The 2009 surveys documented skeletons of adult Tecate cypress in areas that had not burned and it is possible these trees may have died as a result of hydric stress from recurrent drought. Drought-induced shrub and tree mortality is well documented in chaparral ecosystems in southern California, including during the last decade (Oberbauer 1992; Preston and Rotenberry 2006; Kelly and Goulden 2008).

Table 5-1. Annual precipitation recorded in Tustin and Irvine weather stations for the ten year period from 1999 through 2008. Precipitation measurements were obtained from official weather stations in Tustin and Irvine, several miles west of the study area (Western Regional Climate Center 2009).

Year	**Annual Rainfall (inches)**	**Percent of Annual Average Rainfall (1929-2008)**
1999	5.4	43.2%
2000	10.2	81.6%
2001	15.3	122.4%
2002	6.5	52.0%
2003	11.2	89.6%
2004	13.7	109.6%
2005	20.2	161.6%
2006	8.6	68.8%
2007	5.7	45.6%
2008	12.4	103.3%
Ten Year Average (± STD)	**10.9 (±4.7)**	**87.2%**

Tecate cypress seedlings appear to be able to establish in moderate drought years but are susceptible to extremely dry conditions. Following the February 2006 Sierra Peak Fire there was very low recruitment during the October 2006–May 2007 growing season, a period of extreme drought (Tables 5-1 and 5-2). Recruitment also appears variable following the 2002 Green Fire, which burned through 90% of the population. A 2003 census found sparse recruitment throughout the burned area (Harmsworth Associates 2007). This fire also occurred in February, and the remainder of the growing season was extremely dry (Table 5-2). However, the next complete growing season (October 2002 to May 2003) received above average rainfall and seedling establishment was high in some areas, particularly those that had not burned since 1967 (Figures 2-7a and 2-9). The 1967 Paseo Grande Fire, which burned the entire population, provides another indication that Tecate cypress can establish in moderate drought. The first growing season after this fire received 60% of average rainfall, yet recruitment was considered profuse (Armstrong 1978).

Thus, it appears that while Tecate cypress are adapted to conditions in the semi-arid northern Santa Ana Mountains, prolonged and/or extreme drought poses a potential threat to adult survival and seedling establishment following a wildfire.

Climate Change

Tecate cypress could be vulnerable to climate impacts in the future. There is growing evidence and scientific consensus that carbon emissions from human activities are changing the Earth's climate (IDAG 2005; IPCC 2007). Under future climate change scenarios, southern California is predicted to become hotter and potentially more arid (Cayan et al. 2008; Hayhoe et al. 2006; Seager et al. 2006). Depending on the level of carbon emissions, average annual temperature in California is predicted to increase by +1.5°C to +4.5°C by the end of this century (Cayan et al. 2008). In southern California this increase could be even greater, particularly further inland. Temperature increases are predicted to be greater in spring and summer (+1.6°C to +6.4°C) than in winter (+1.7°C to +3.4°C). There is some uncertainty about future precipitation patterns, although most

Table 5-2. Long-term average precipitation (1929-2008) compared to precipitation during the growing seasons following wildfires that burned portions of the Santa Ana Mountains Tecate cypress population. Precipitation measurements were obtained from official weather stations in Tustin and Irvine, several miles west of the study area (Western Regional Climate Center 2009). Lower than long-term average amounts of rainfall are highlighted in bold.

Growing Period	**Period**	**Long-term Rainfall Average (inches)**	**Paseo Grande Fire 10/29/1967 Post-fire Rainfall (inches)**	**Paseo Grande Fire 10/29/1967 Post-fire Rainfall as Percentage of the Long-term Average**	**Gypsum Fire 10/9/1982 Post-fire Rainfall (inches)**	**Gypsum Fire 10/9/1982 Post-fire Rainfall as Percentage of the Long-term Average**	**Green Fire 2/9/2002 Post-fire Rainfall (inches)**	**Green Fire 2/9/2002 Post-fire Rainfall as Percentage of the Long-term Average**	**Sierra Peak Fire 2/6/2006 Post-Fire Rainfall (inches)**	**Sierra Peak Fire 2/6/2006 Post-fire Rainfall as Percentage of the Long-term Average**
Partial Growing Period Following February Fires	February-May	6.25	NA	NA	NA	NA	**1.5**	**24.0%**	**5.33**	**85.3%**
First Complete Growing Season Following Fire	October-May	12.50	**7.55**	**60.4%**	23.15	185.2%	15.60	124.8%	**3.29**	**26.3%**

models are now predicting a decrease in precipitation with more frequent and longer droughts (Seager et al. 2007; Burke and Brown 2008). These changes in temperature and precipitation could increase soil temperature and reduce soil moisture, particularly in the summer, which could lead to increased hydric stress for trees during drought periods.

Increased spring and summer temperatures combined with an earlier snowmelt have been associated with an increase in fire frequency, wildfire duration, and fire season length in the western United States starting in the mid-1980s (Westerling et al. 2006). Wildfire activity is likely to increase in most areas of California, although the predictions for southern California are more uncertain as a warmer and drier climate could decrease plant biomass and reduce the incidence of fuel-driven fires (Westerling et al. 2008). It is also unclear whether Santa Ana winds might be altered in a warming climate. If Santa Ana winds became less frequent or weaker, this could reduce the potential for large wind driven fires.

Changing climate conditions could threaten Tecate cypress in the Santa Ana Mountains if drought causes seedlings to fail to establish and adults and juveniles to experience poor survivorship or if fire activity is further accelerated. The northern Santa Ana Mountains are likely to be less effected by climate change than more inland mountain ranges. The extent to which Tecate cypress populations are threatened by climate change requires further investigation, including an evaluation of how the species might respond to future climate scenarios. If environmental conditions in their current location are likely to deteriorate, it is important to identify climate refugia where the species might shift its distribution in response to changing climate.

Air Pollution

Air pollution contains ozone, mercury, nitrogen oxide, sulfur dioxide and other harmful compounds, that when deposited onto lakes, rivers, plant foliage, and soils can adversely affect native ecosystems (Cowling 1989; Takemoto et al. 2001; Fenn et al. 2003a; Phoenix et al. 2006; Lovett and Tear 2008). High levels of air pollutants may lead to changes in community structure and composition and are an emerging threat to conserving biodiversity at the global scale (Phoenix et al. 2006). In some cases, air pollutants, such as ozone and acid rain, may directly injure plants or through chronic effects reduce their ability to withstand other stresses, leading to the decline of sensitive species (Takemoto et al. 2001; Lovett and Tear 2008). Nitrogen oxide may indirectly affect native plant communities by altering soil nutrient cycles, reducing disease resistance, and enhancing the competitive abilities of some species over others, also leading to the loss of plant diversity (Fenn et al. 2003a; Weiss 2006; Phoenix et al. 2006). Nitrogen deposition affects species differently, with some species increasing in abundance and others disappearing. The mechanisms by which this change occurs vary by species and community (Suding et al. 2005).

Air pollution is a well documented problem in urbanized Southern California, with the deposition of airborne pollutants quite high in the Los Angeles Basin and inland areas to the east (Takemoto et al. 2001; Fenn et al. 2003b; Tonneson et al. 2007; Weiss 2008). The greatest concentration of air pollutants in Orange County is in the northern portion, particularly along the Santa Ana River Canyon and Highway 91 transportation corridor (Tonneson et al. 2007). Air pollution originating from industrial and vehicular sources in the Los Angeles Basin combines with high levels of emissions from the Ports of Long Beach and Los Angeles, and is carried by winds flowing east through northern Orange County into Riverside and San Bernardino Counties. The prevailing winds cause the northern Santa Ana Mountains to receive relatively high levels of pollutants, such as ozone and nitrogen oxides. The detrimental effects of air pollution on mixed conifer forests in the southern California region has been well documented, with the death of many ozone sensitive trees in the San Bernardino mountains and a change in the composition of understory herbaceous species associated with nitrogen deposition (Takemoto et al. 2001; Allen et al. 2007). The effects of ozone vary among species, with some pine species particularly vulnerable to injury while some cedars and firs are more resistant, leading to a shift in species composition. Nitrogen deposition in southern California in combination with altered fire regimes has also been implicated in facilitating the invasion of exotic, annual grasses into southern California coastal and desert shrublands (Allen et al. 1998; Allen et al. 2008; Talluto and Suding 2008).

Little is known about whether air pollutants are affecting Tecate cypress, either through injury to trees or indirectly through effects on nutrient soil cycles and invasive plant dynamics. During the 2009 surveys, there were no reports of injury or stress to trees attributable to ozone or other pollutants. Currently, there does not appear to be a serious problem with invasive annual grasses (see next section). However, given the proximity of the northern Santa Ana Mountains Tecate cypress population to high concentration of air pollutants along the Santa Ana River Canyon/Highway 91 corridor, it is advisable to monitor the population periodically to assess potential impacts from air pollutants.

Invasive Plants

Invasion of native plant communities by exotic plant species has a well-established history and poses a significant and costly problem for land managers conserving sensitive natural resources (Bowler 2000; Pimental et al. 2005). In the semi-arid ecosystems of southern California extensive efforts are undertaken by land managers to control weed species and restore native plants. The Nature Reserve of Orange County has conducted an Exotic Plant Control Program since 1997 (Harmsworth 2009) that typically costs $250,000 annually. This program is undertaken for the benefit of native plant communities and sensitive plant and animal species conserved under the NCCP/HCP.

Invasive plants adversely impact natural communities, they can outcompete native species, alter ecosystem functions, and change plant community composition and structure (D'Antonio and Vitousek 1992; Keeley et al. 2005; Talluto and Suding 2008). Mediterranean annual grasses alter hydrological processes leading to poor infiltration of rainfall, drying of soils, and increasing runoff and erosion (D.Antonio and Vitousek 1992; DiTomaso 2000; DiTomaso et al. 2006; Jigour 2009). Invasive grasses and forbs can alter fire regimes by increasing fire frequency (D'Antonio and Vitousek 1992; Keeley 2006). In chaparral, high fire frequency further opens up the shrub community to invasion by exotic annual grasses and forbs (Zedler et al. 1983; Barro and Conard 1991). In intact shrublands, fire typically burn as intense crown fires, whereas when grasses are introduced into the system, fires burn more on the surface with a reduced intensity (Keeley et al. 2008). This could increase risk to Tecate cypress seedlings, if invasive grasses are present they may carry fire to the seedlings. Grasses are also highly flammable which increases the potential for ignition and can lead to more fires. This increase in fire frequency and reduction of fire severity provides a positive feedback facilitating conversion of shrubland to nonnative annual grassland. An unusually short fire return interval can cause the failure of many shrub species to resprout or reseed (Zedler 1983). In contrast, woody plants can competitively displace non-native grasses under a natural fire regime which allows shrubs the time to mature and produce seeds and to shade out grasses (Keeley et al. 2005).

Based on the 2009 surveys, invasive annual grasses and forbs do not appear to be abundant in the area supporting the main Tecate cypress stand, but with more frequent fire could become a threat. Invasive grasses were abundant at a Cleveland National Forest site that burned in 2006, with only skeletons of burned adults and no seedlings.

Human Activities

Human activities within the NCCP/HCP have the potential to directly injure or kill Tecate cypress or to indirectly cause damage by altering natural ecosystem processes. Illegal off-road vehicle activity and the creation and use of illegal trails could lead to the trampling and injury or even death of seedling, juvenile, and adult trees. Illegal trails can compact the soil and also cause erosion, potentially altering hydrological processes and impacting adjacent trees.

The use of firearms for illegal target shooting and hunting could spark fires and threaten the Tecate cypress population with wildfire. There is also the potential for accidental or arson-caused fires by people in the vicinity of the stands during high fire risk conditions. Other threats to the Tecate cypress from unauthorized activities in the northern Santa Ana Mountains include illegal fireworks, smoking, and campfires, all of which could ignite wildfires. The unauthorized collection of cones and seeds by visitors to the stand could also threaten the population's seedbank.

Illegal marijuana growing operations are a problem throughout public lands in southern California and can cause fires and vegetation disturbance. Vegetation is often removed to make way for the plants, water is diverted from streams, and illegal campsites established. This type of activity is unlikely to occur near the main stand of Tecate cypress because of the lack of water. However, this could be a concern in riparian habitat at the bottom of Gypsum Canyon, where there are small numbers of large Tecate cypress.

6.0 FIRE MANAGEMENT RECOMMENDATIONS

The following management strategies and specific management recommendations are based upon information regarding the current status of the Tecate cypress population (Section 2) and the results of the fire risk assessment and dynamic population modeling (Section 3) and habitat assessment (Section 4). Recommendations were developed and reviewed by the TCMC. This section also incorporates recommendations for management actions found in the Nature Reserve of Orange County's Fire Management Plan (NROC, in prep) and in the Wildland Fire Ignition Reduction Strategy developed for Irvine Ranch Lands (Irvine Ranch Conservancy 2008). The intent is to implement these management actions to the extent feasible, given the availability of resources and personnel. The TCMC will meet annually to identify specific management actions to prioritize and to identify available resources and potential funding opportunities to implement these management actions. The TCMC will collaborate to apply for funding and respond to opportunities to leverage funds to manage Tecate cypress in the northern Santa Ana Mountains.

Strategic Fire Management Recommendations

Protect the Entire Population from Frequent Fires

Based upon the fire risk assessment and population modeling (Section 3) a primary recommendation to enhancing the long-term persistence of Tecate cypress in the Santa Ana Mountains is to implement fire management strategies to protect the entire extent of the population. A fire return interval of at least 35 years is necessary for individuals to reach reproductive maturity and ensure that there is a sufficient seedbank for replacement. A fire return interval of less than 35 years will not support a stable or growing population. Although initially considered, the results do not support the implementation of small-scale fire management strategies for two reasons. First, fire susceptibility is similar throughout the extent of Santa Ana population which makes it challenging to prioritize where to allocate resources. Secondly, since the Tecate cypress population is most sensitive to changes in the size of the seedbank after a fire, it is recommended that refugia be connected to areas that are suitable for recruitment following a fire. This means protecting areas with active recruitment supporting juvenile trees. These areas are located primarily in the Coal Canyon Ecological Reserve. Devoting resources to protecting current refugia supporting adults is not as important as ensuring that seeds produced in these refugia reach burned regions where recruitment is likely.

The findings of the population modeling are based on strong assumptions about cone production and population connectivity. Changes in cone production over time and dispersal rates are two little studied aspects of the Tecate cypress life cycle. Land managers should evaluate the year-to-year variability in cone production, seed viability and recruitment during years without fire. It is recommended that the Tecate cypress population be periodically monitored over the long-term to improve our understanding of the life history of this species. With long-term data it will be possible to provide a more refined estimate of the true sensitivity of this population to changes in environmental conditions and fire regime.

Establish a Widespread Population So Individuals Can Attain Reproductive Maturity

Management strategies should be designed in such a way that most Tecate individuals will not experience fire for at least 30-35 years; allowing them to reach reproductive age and ensure seed availability for replacement after a fire. Considering the unpredictability of large-scale Santa Ana Wind driven fires, which currently can burn through the entire population, it is recommended that the population be spread into regions incorporating large-scale differences in the expected number of fires. By establishing a more widely distributed population, a greater proportion of individuals are likely to escape a fire event and to attain reproductive maturity. It is advisable to divide the area where Tecate cypress has been historically reported into three strategic regions. One region supports good growing conditions for Tecate cypress with relatively low fire risk and corresponds with the northwestern and northeastern flanks of Coal and Gypsum Canyons. A second area with higher fire risk, but potentially good habitat is along Fremont Canyon. The third area with low fire risk and relatively low habitat suitability, but with a demonstrated capacity to support planted populations, comprises high elevation areas along the east flank of the Santa Ana Mountains in the Cleveland National Forest. This is also an area that is suggested to become more suitable for Tecate cypress under future climate change, if conditions become warmer and drier as predicted. However, further research is needed to evaluate the response of Tecate cypress to future climate change scenarios and identify climate refugia.

Specific Fire Management Recommendations

The single most important thing that land managers can do to ensure the continued persistence of Tecate cypress in the Santa Ana Mountains is to reduce fire frequency in cypress stands.

Actions to Reduce Fire Frequency

Land owners, managers and members of the TCMC should coordinate and work together to implement the following management measures in order to reduce fire frequencies in the northern Santa Ana Mountains.

Recommended Tecate Cypress Management Committee Implementation Actions

- The TCMC should work with transportation agencies to implement fire-hardening measures along the south side of Highway 91, the east side of the Highway 241 Toll Road and other major roadways and turn-outs adjacent to NCCP lands in the northern third of the Central Reserve. Potential fire-hardening methods to prevent wildfire ignitions include k-rails, concrete walls and hardscaping adjacent to roadways.

- The TCMC should work with land owners and managers to design, create, and annually maintain a weed-free buffer at the border of the Central Reserve adjacent to the south side of Highway 91 and to the east side of Toll Road 241. The potential for ignition of fires is very high in annual grasses and forbs, as they comprise flashy fuels that can easily ignite and carry fire into native habitats. The intent of this recommendation is to reduce invasive annual grasses and forbs in order to reduce the chance of fires igniting near the road and moving into the Reserve.

- The TCMC should coordinate and work with utility companies to reduce the risk of powerline ignited fires, particularly for local distribution lines with wood poles. This could include replacing old powerpoles, retrofitting powerpoles to reduce the potential for bird electrocutions, and undergrounding local transmission lines in areas vulnerable to Santa Ana Winds, such as in the vicinity of Coal Canyon. Powerlines should be regularly inspected and maintained to reduce chances of accidental fire ignition.

- The TCMC should coordinate with the Orange County Fire Authority to ensure that the fire roads leading to the Tecate cypress population are maintained to standards that will support fire agency access during a wildfire. This includes the possibility of fuel thinning in selected areas to improve safety for fire fighting personnel and to provide defensible fire breaks around the perimeter of the Tecate cypress stand. Any fuel reduction activities could only be implemented if there is annual maintenance that precludes the establishment of invasive annual grasses and forbs that provide flashy fuels and could further endanger the Tecate cypress population.

- The TCMC should identify and prioritize for restoration to native shrubland those areas in the Central Reserve near roads and other high risk ignition sites that are dominated by flammable non-native annual grasses and other weeds at risk of igniting and carrying fire to the Tecate cypress population.

- The TCMC should look for ways to facilitate or undertake a study to test the effectiveness and cost of different fire prevention measures, particularly near roads. The results of this study should be used to inform implementation of fire prevention methods in the Central Reserve.

Recommended Tecate Cypress Management Committee Cooridnation and Planning Actions

- Hold an annual pre-fire season meeting with the TCMC, fire agencies, and utility companies to assess fire risk and fire preparedness and make recommendations for management actions. This includes evaluating the current status of the Tecate cypress population, public access restrictions, fire road maintenance and access, planned Fire Watch activities, fuel moisture levels, fuel loads, fuel breaks, fire fighting strategies, and fire prevention efforts.

As resources and time allow, the following measures should be implemented as feasible. It is important to note that the members of the Tecate Cypress Management Committee have limited resources. However, the group will work to attain additional resources and take advantage of opportunities in order to achieve the following goals

- The TCMC should work with the owners of the proposed housing development at the base of Gypsum Canyon and the Anaheim Fire Department to develop fire prevention strategies and measures.

- The TCMC should work with Orange County Fire Authority and other organizations to develop guidelines and coordination of Fire Watch patrols in the northern Santa Ana Mountains during red flag events. This would include prioritizing key areas to patrol based upon past ignition history, weather patterns, and fire related conditions that exist at the time.

- The TCMC should participate in developing a public outreach program to educate people on the need to prevent fires in the northern Santa Ana Mountains. This could include developing signage, brochures, Tecate cypress stewards and a Neighborhood Watch.

Recommended Land Owner and Land Manager Actions

- There should be no prescribed fires within Tecate cypress stands in the northern Santa Ana Mountains, unless the fire regime is altered and fires become so infrequent that the persistence of the population is threatened by lack of reproduction and recruitment of younger cohorts into the population.

- Control flammable invasive annual grasses that provide flashy fuels in landscaped and natural lands adjacent to roads. Exotic grasses easily ignite to start a wildfire. The TCMC should work with transportation agencies to facilitate this maintenance along road right of ways and land owners/managers should maintain NCCP lands adjacent to roads.

- As funding becomes available, land owners and managers should restore to native shrubland those high priority areas invaded by non-native annual grasses and forbs and other flashy fuels identified as threats to the Tecate cypress population by the TCMC.

- Land owners and managers should increase their vigilance and patrols in the Central Reserve during high fire risk conditions, particularly red flag warning periods, in order to enforce access restrictions, prevent unauthorized activities and reduce opportunities for arsonists to ignite fires.

- During periods of high fire risk, restrict the use of power tools, mowers, chain saws and other equipment used for routine maintenance activities that could ignite fires in the Central Reserve. The use of power tools for activities that can reduce fire risk in a safe manner could be allowed under appropriate safeguards.l

- Limit land management, maintenance, and research access and activities in the Central Reserve during high fire risk periods. Land owners and managers should engage only in activities essential for fire prevention and natural resource protection.

- Land owners and managers should install remote surveillance cameras to monitor human activity at access gates and along roads leading to the Tecate cypress population.

- Land managers should carry fire extinguishers in their vehicles when driving to the Tecate cypress stand in case of accidental ignition by a management vehicle.

- Land owners and managers should maintain access roads to the Tecate cypress stand so there are no nonnative grasses or other exotic herbaceous plants to ignite when vehicles travel on the road during the fire season.

Recommended Access and Activity Restrictions

- Prohibit public access, including guided tours and other events, in the northern Santa Ana Mountains during high fire risk periods and all red flag conditions. Land owners, managers, and easement holders should develop and agree to a set of policies and work together to enforce access restrictions during periods of high fire risk. During drought years and periods when fire risk is high, public access could be restricted throughout the summer and fall months.

- Prohibit and strictly enforce a ban on smoking on all Central Reserve lands, including trail heads and staging areas.

- Prohibit and strictly enforce a ban on shooting of fire-arms throughout the Central Reserve, including target shooting and hunting.

- Prohibit and strictly enforce a ban on recreational off-road vehicle activity in the Central Reserve.

- Limit public access to pullouts off Highway 91 and the 241 Toll Road that are adjacent to the Central Reserve, and in particular the pullout at the bottom of Gypsum and Coal Canyons.

Actions to Suppress Fires and Protect the Tecate Cypress Population

- The TCMC should develop a working committee (Tecate Cypress Fire Committee) with representative members from the fire agencies (e.g., Orange County Fire Authority, US Forest Service, California Department of Forestry, and Anaheim Fire Department). The goal of this committee would be to develop a tactical fire plan for the Tecate cypress stands. It is important that this plan is feasible for agencies to adopt and that it prioritizes protection for Tecate cypress. This plan would recommend actions that fire fighters and lands managers could take before, during and after a wildfire. Some issues to be covered include fire-fighting techniques and strategies and the use of fire in the vicinity of Tecate cypress stands, such as prescribed burns to reduce fuels and backfires to help control the spread of wildfires.

- In the event of a fire, NROC's designated lead resource advisor will coordinate with Orange County Fire Authority and land managers to provide technical advice and recommendations regarding tactical fire suppression activities.

- The Tecate Cypress Fire Committee and the Nature Reserve of Orange County Fire Management Plan, Volume 2 (NROC, in prep), will provide fire-fighting personnel with recommended locations for bulldozer lines in the vicinity of Tecate cypress stands. Placement of these bulldozer lines will be designed to minimize harm to the trees and enhance fire-fighting capabilities.

- Fire fighting activities, such as the construction of hand lines, backfires, fire retardent, foam and wetting should be consistent with the recommendations of the Tecate Cypress Fire Committee and the Nature Reserve of Orange County Fire Management Plan, Volume 2. These activities should be conducted outside the Tecate cypress stand to avoid impacting trees.

- If in the future, fire prevention and suppression measures effectively increase fire return intervals beyond 30-35 years, then the TCMC should meet to evaluate whether active management should be taken to allow a fire to burn through the stands to prevent senescence and encourage reproduction.

Post-Fire Response

Following a wildfire in the Tecate cypress population, the following actions should occur:

- The TCMC should make a field visit to assess fire impacts and formulate immediate remedial actions necessary to protect the population.

- NROC will coordinate performance of a post-fire population risk assessment that will guide implementation of specific management actions for population recovery (i.e., seed collection, rehabilitation measures for fire suppression impacts, erosion and invasive species control, restoration measures).

- The TCMC will meet to review the report and coordinate specific actions by the various landowners.

- NROC in conjunction with the TCMC will conduct annual post-fire Tecate cypress monitoring to assess the population's response to the fire. This monitoring will include mapping remnant populations, refugia and seedling recruitment.

- At the annual TCMC meeting, an assessment will be made of the effectiveness of post-fire management actions on population recovery.

- Collect seeds following fire to aid in restoring populations in the Central Reserve following policies formulated from recommendations in Section 7.

7.0 RESEARCH, MONITORING, RESTORATION & CONTINGENCY

RECOMMENDATIONS

There are a number of gaps in our knowledge of Tecate cypress life history traits, environmental requirements for seedling establishment and growth, and specific restoration techniques. It is important to gather additional information through experimental studies and additional population monitoring to most effectively and cost efficiently manage the population over the long-term. The amount of seed available for restoring the northern Santa Ana Mountain population of Tecate cypress is limited (see seed collection section, below), thus it is important to determine the most successful restoration techniques to minimize wasting seeds with inefficient or ineffective techniques. As a result, this management plan takes a two-phased approach to managing the northern Santa Ana Mountains Tecate cypress population. Phase I involves filling knowledge gaps and developing more specific recommendations for selecting and prioritizing restoration sites, guidelines for seed collection, methods for establishing seedlings (e.g., planting seeds versus seedlings) and other aspects of achieving restoration success such as supplemental irrigation and planting density. Optimally, these methods will be tested across the other southern California populations for comparative purposes.

This plan initiates restoration during the first phase, starting with smaller scale planting trials and in Phase II progresses to restoration activities that expand the population on a larger scale, both within and beyond the historic distribution. Based upon our current knowledge, it is predicted that such a population expansion could help the population persist in response to climate change and to improve resilience if fire return intervals are less than 30-35 years. This phased approach takes into account the neccessity of quickly beginning restoration projects so that trees can begin establishing and growing to maturity and better contribute to population recovery after a fire. It is understood that while it is important to gather detailed knowledge on the most effective and cost efficient methods and to wisely use our available seed supply, this will not delay implementation of restoration projects at a small scale. This plan identifies specific areas that are high priority for restoration within the existing population footprint. Experimental trials can be established at these locations in order to begin augmenting the population while simultaneously collecting data to establish methods for expanding the population outside its' current distribution. In addition to trials focusing on methods of restoration, research is also needed to determine those environmental factors that limit the survival of seedlings. Factors such as precipitation, temperature, soil moisture, soil characteristics, and competition are needed to more narrowly refine suitable areas for restoration within the historic range as well as in new areas that might provide greater resilience to fire and changing climate.

In addition to research and restoration recommendations, this section provides monitoring recommendations and establishes contingency measures that could help ensure long-term persistence of Tecate cypress in the face of another large-scale wildfire or other catastrophic event in the northern Santa Ana Mountains.

Research Recommendations

Knowledge Gaps and General Research Needs

Predictions from the habitat modeling and fire risk assessment were combined to identify priority areas for restoration (Figures 4-8 through 4-10). The habitat models did not predict substantial suitable habitat outside the current distribution of Tecate cypress. Thus, additional knowledge is needed to identify areas suitable for expanding the distribution of the Tecate cypress population in the future. In general, the areas where Tecate cypress currently occurs are at intermediate elevations mostly on northern slopes, with intermediate values of precipitation and temperature during the growing season, and on shallow soils with high percentage of sand and low vegetation coverage. However, there are several important limitations to the model results because of the highly aggregated nature of the existing population locations used to construct the models. The utility of our modeling approach could be dramatically improved by several extensions to the project.

A more extensive exploration of habitat characteristics would greatly increase our power to identify habitat suitability. Incorporating other areas with current Tecate populations, such as those in the Otay and Guatay Mountains, Tecate peak in San Diego County, and where possible, scattered stands in Baja California, Mexico, would reduce the problems associated with data aggregation in this current project. It would be particularly useful to include soil attributes associated with these locations, and information on presence of other abundant native species such as *Salvia mellifera*, *Adenostoma fasciculatum*, and *Ceanothus sp.*, which were the most abundant species in our study area. To address the nature of environmental restrictions it is recommended that habitat models be developed that incorporate occurrence data from across the range of the species and predicts suitable habitat over a larger study area. Using these models calibrated under current climate conditions, potential habitat for Tecate cypress should be modeled under future climate change scenarios. The results of this modeling could be used to identify areas for potential restoration that are projected to be future climate refugia.

It is important to estimate the intensity with which Tecate cypress has been sampled in the study area when assessing the validity of these habitat models. Historical records of Tecate cypress along the Santa Ana Mountains consistently identify the current location of this species as the only location where this species occurs in this region. This restrictive distribution implies that the establishment of this species could be truly limited to a particular area rather than to a sampling bias of the models themselves. Tecate cypress have been established through planting in areas with low suitability predictions from our habitat models. Although the habitat suitability values may capture conditions that favor natural establishment, this result implies that environmental variables used in this model do not fully capture conditions that favor Tecate cypress survival when planted. These planted populations have not spread beyond their original extent to expand the range of Tecate cypress in the Santa Ana Mountains. The plantings demonstrate the ability of Tecate cypress to establish in less suitable areas under certain conditions, but indicate there may be limitations from expanding into a wider area, perhaps because of drought and competition with other vegetation types at the seedling stage. Thus, it is recommended that projects be developed involving the outplanting of Tecate seedlings along environmental gradients to evaluate whether the environmental restrictions exist that are identified in these habitat models. If most of the habitat restrictions identified by these models are due to low dispersal or strong environmental sensitivity in early germination, these restrictions would not apply to planting trees in restoration projects.

Tecate cypress appear to tolerate a variety of soil conditions across their range. This characteristic could facilitate recovery strategies that depend upon ex-situ cultivations and subsequent re-introduction, even when these re-introductions are planned outside current Tecate cypress locations. The habitat models consistently identified soil characteristics as relevant to predicting habitat suitability for seedlings; however, model comparisons suggest soil characteristics might not be highly relevant at the scale of our models. First, the weight of soil variables during model training is mostly driven by the aggregated nature of our modeling points. Second, when depth to a restrictive layer is not included in the model, vegetation coverage had the highest contribution during model training, followed by minimum growing season temperature (Table 4-6). This model achieved similar performance to the full model, suggesting that soil depth is not as important for predicting Tecate cypress seedling distribution as suggested by its percent contribution in the full model. In fact, the group-specific model with only soil characteristics shows lower performance values than the full model. In addition, soil characteristics are important for modeling adult habitat suitability but less important for seedling suitability, despite adult locations showing wider variability in soil characteristics. This could indicate that seedling recruitment is less limited by resource competition and more by suitable microsites. Thus, in order to fully evaluate Tecate cypress edaphic restrictions and test these ideas, planting trials over a range of soil characteristics would be appropriate.

Current recruitment patterns reflect the effects of fire history, habitat characteristics and pre-fire structure on post-fire recovery. Thus, resources should be devoted to identify areas with optimum growing conditions where few but highly productive adults guarantee seed supply after fire. With predictions of increased drought frequency and severity, identifying areas that are less drought-prone may be essential as the probability of a drought during the post-fire recruitment window is relatively high.

The fire assessment and dynamic growth modeling showed that growth conditions within the current distribution of Tecate cypress population have little effect on long-term population dynamics. The 2009 census identified areas with the same fire history transitions but with different population structures, however, these differences did not translate into significantly different population characteristics. If the conservation goal is to expand the population beyond the current distribution, it is important to accurately estimate variability in growth conditions throughout the northern end of the Santa Ana Mountains. Experimental planting trials should be conducted to detect the lower tolerance limit for which Tecate cypress populations show stable or positive population growth. The current analyses are preliminary in estimating this threshold, as they are solely based on the current population structure at specific locations. Growth rates were also not explicitly measured across the landscape. Given that long-term population dynamics are highly sensitive to survival transitions in the first size classes, is is recommended that basic research on this species be extended to fully evaluate the effect of different habitat conditions on Tecate cypress life history transitions. A general strategy in the absence of such information is to give priority to management actions that improve the growth and survival of already established juveniles.

Phase I: Experimental Trials to Determine Environmental Restrictions and Specific Methods for Restoration

The TCMC will oversee experimental trials and the collection of additional population monitoring data and use these results to develop more specific recommendations for the Phase II implementation of restoration over a larger scale. Land owners/managers that would like to conduct an experimental trial shall submit a proposal to the TCMC for review and approval by NROC and the wildlife agencies. In addition, the TCMC may also jointly initiate restoration experiments involving multiple land owner and managers.

- Priority restoration sites for Phase I restoration experiments are identified in Figures 4-8 through 4-10. These are areas suitable for seedlings based on environmental relationships at locations where Tecate cypress currently occur and on the lower probability of burning during a fire in Santa Ana conditions. These areas are recommended for initial restoration efforts.

- Experimental trials should be undertaken to determine the effects of soil and climate constraints on seedling establishment and growth to evaluate whether suitable habitat is as restrictive as the seedling habitat models indicate. In particular, the performance of Tecate cypress seedlings under a range of soil, climate and vegetation cover conditions should be assessed. It is anticipated this would be a multiple year study so that the effects of annual variation in growing conditions are assessed. The important factors limiting seedling establishment should be identified. It would be useful to determine whether the environmental restrictions may be much less severe with planned plantings relative to natural recruitment.

- The use of supplemental water to aid in seedling establishment should be investigated under drought conditions to determine the costs and benefits for population recovery. Based upon the results of this study, procedures and guidelines should be developed for supplemental watering.

- Based upon the results of models constructed with only vegetation variables, Tecate cypress may be limited by competition with other plants at the seedling stage. Experimental restoration trials should be undertaken to evaluate whether site preparation measures such as thinning and trimming of adjacent shrubs and control of invasive annuals and forbs affects seedling growth, establishment and recruitment.

- Conduct field trials to determine how best to establish new stands of Tecate cypress under different environmental conditions. This project should evaluate the effectiveness and costs of planting seeds versus seedlings, site preparation procedures, and seed collection, storage and germination methods. The results of this study will be used to develop specific restoration guidelines.

- Work with other researchers and land managers to coordinate studies of Tecate cypress populations in southern California and northern Baja California to better understand habitat constraints and population dynamics.

Phase II: Implementation of Larger-scale Restoration and Population Expansion

To facilitate long-term persistence of the northern Santa Ana Mountains Tecate cypress population, it is important to augment the population within its current distribution and then to establish additional populations within the historic range as well as new areas. Identification of sites for restoration should be guided by information presented in this plan that is augmented by the results of further habitat modeling and experimental planting trials and studies (see above section). At the annual pre-fire TCMC meeting, land owners/managers should identify candidate sites for restoration on their land and submit these sites for review and approval by NROC, the wildlife agencies and the TCMC.

Areas Prioritized for Restoration within the Current and Historic Distribution

During Phase I experimental trials restoration trials will be initiated in areas identified as high restoration priority in Figures 4-8 through 4-10. During Phase II, completing restoration in these areas will be a high priority. The current Tecate cypress population is highly fragmented because most suitable sites for restoration are upslope of the refugia that support many of the cone bearing adults. Thus, a management challenge is to enhance seed supply in higher elevations where recruitment is possible. It is important to consider this when identifying specific sites for restoration in Phase II.

Frequent large fires put the entire population at risk, particularly when the majority of the current population will not reach maximum seed production for many years. While there are natural refugia within the current distribution, these are not enough to ensure adequate recovery following a large fire, particularly if it occurs in the near future. A more widely distributed population structure is recommended to ensure that a greater proportion of individuals can escape each fire and grow to reproductive maturity. As recommended in Section 6, it is advisable to divide the historic distribution of Tecate cypress into three strategic regions that are a high priority for restoration in Phase II. One region supports good growing conditions for Tecate cypress with relatively low fire risk and corresponds with the northwestern and northeastern flanks of Coal and Gypsum Canyons. A second area with higher fire risk, but potentially good habitat is along Fremont Canyon. The third area with low fire risk and relatively low habitat suitability, but with a demonstrated capacity to support planted populations, comprises high elevation areas along the east flank of the Santa Ana Mountains in the Cleveland National Forest.

Eventually, it will be desirable to identify additional restoration areas outside of the historic distribution of Tecate cypress in order to spread the population over a greater area to reduce threat of fire and to provide refugia under changing climate conditions. These areas should be identified and prioritized by the TCMC. Selection and prioritization of restoration sites will be based upon the results of experimental planting trials documenting environmental constraints, upon habitat modeling incorporating data from across the species range, and upon projections of habitat models for climate refugia under future climate scenarios.

Population Monitoring Recommendations

It is recommended that the northern Santa Ana Mountain Tecate cypress be monitored annually for five years to establish year-to-year variability in cone production, seed viability and recruitment during years without fire. Once these baseline data are collected, the population should be monitored every five years. The monitoring should incorporate the methods described in Section 2 for the 2009 surveys. Measurements should be taken at transects measured in 2009, with additional sampling transects extended into portions of the population that was not surveyed. Data should be collected on the size and number of seedlings and adults, cones per adult, and the other factors assessed during the 2009 surveys. In general, monitoring the Tecate cypress population over the years will greatly improved our understanding of the life history of this species. With long-term data it will be possible to have a much better estimation of the true sensitivity of this population to changes in environmental conditions and fire regime.

Contingency Measures

The northern Santa Ana Mountain population of Tecate cypress is vulnerbale to recurrent fires and other catastrophes, such as the emergence of a new disease pathogen or insect pest, and several contingency measures are recommended to help recover the population in case of such an event.

Collect Seeds from the Wild Population and Establish a Tecate Cypress Nursery Population as a Contingency Seed Source

On an on-going basis, seeds should be collected from adult trees to store for use in a contingency situation and to provide for restoration and expansion of the Tecate cypress population. The TCMC will oversee and coordinate the use of these seeds to establish a nursery population of Tecate cypress that will eventually represent samples from individuals distributed throughout the Santa Ana Mountain population. The seeds will be grown into adults that when reproductively mature may be used as a seed source for emergency restoration, such as might occur if most or all of the Tecate cypress population burns too frequently and does not recover. Seeds will be harvested and made available to land owners based upon a needs assessment to re-establish populations in the highest priority areas. This assessment will be conducted by NROC and the wildlife agencies in consultation with the TCMC. Areas would be selected for seeding based on an assessment of the distribution of the Tecate cypress population at the time of the contingency and on the suitability of available restoration sites. Research is recommended to obtain more information on seed viability over time, from burned versus unburned cones, and techniques for handling and storing seeds.

A nursery population of Tecate cypress should be set up in an area within an urban core near the Central Reserve. Proximity to the Central Reserve ensures more similar climatic conditions than would be experienced closer to the coast. By establishing the nursery within an urban perimeter and away from wildlands, there is increased probability the nursery population will survive a large-scale fire in the wildlands. This population could provide a supplemental seed source for the wild population should that be necessary. The TCMC will identify potential nursery sites and organizations responsible for maintaining the nursery population. The TCMC will also develop guidelines to identify and prioritize the sources of Tecate cypress seeds and/or seedlings to be used to establish the nursery population.

Seed Collection Policies

Seeds should be collected on a rotating basis from mature trees in absence of fire. Following Rancho Santa Ana Botanical Gardens Seed Collection Guidelines (Wall 2009), a small proportion of seeds will be collected from each individual tree. This will reduce over-representation of a particular genotype in restoration areas and avoid extensive seed harvesting that might detrimentally affect the population from which the seeds are collected. These seeds will be used to establish new populations and augment historic populations within the Central Reserve.

Collected seeds should be archived and stored so as to reduce impacts to seed viability. Seeds should be stored at two to three institutions to minimize the risk of losing all seeds in case of an unforeseen event at a single institution. The seeds should be used when they are most viable, within one to two years of collection. Candidate sites for seeding and restoration will be identified by the land managers based on the distribution of Tecate cypress at that time and on habitat suitability. NROC and the wildlife agencies will review and approve candidate restoration sites in consultation with the TCMC.

8.0 Draft Interagency Cooperative Management Agreement

To facilitate effective conservation and management of Tecate cypress in the northern Santa Ana Mountains, a Memorandum of Understanding (MOU) has been drafted for review and approval by the various land owners, land managers and organizations responsible for the conservation of these Tecate cypress populations. The TCMC will work to finalize and adopt this agreement among the partner organizations.

DRAFT

MEMORANDUM OF UNDERSTANDING

FOR THE MANAGEMENT AND CONSERVATION OF TECATE CYPRESS IN ORANGE COUNTY, CALIFORNIA

THIS MEMORANDUM OF UNDERSTANDING ("MOU") is entered into on this _ day of ______, 2010, by and between the Irvine Company ("TIC"), the California Department of Fish and Game (CDFG), a state land owner, manager and regulatory agency, a private company, the Cleveland District of the USDA Cleveland National Forest Trabuco Ranger District (USFS), a federal land owner and manager, Orange county Parks, a county agency, the United States Fish and Wildlife Service (USFWS), a federal regulatory agency, the Irvine Ranch Conservancy (IRC), a non-profit corporation, the Nature Conservancy (TNC) a non-profit corporation and the Nature Reserve of Orange County (NROC), a non-profit corporation.

Recitals:

Tecate cypress is a rare species of tree limited to several locations in the northern Santa Ana Mountains of Orange County, California, which is a Covered Species under Orange County's Central and Coastal Natural Community Conservatin Plan/Habitat Conservation Plan (NCCP) and is considered by the California Native Plant Society as a Category 1B species.

Tecate cypress is a priority species for conservation among the Parties to this MOU and is threatened by fire, drought, and is vulnerable to other disturbances as it occurs in small, isolated populations restricted to several locations in southern California; and

The land on which Tecate cypress may be found is part of a complex of protected open space known variously as the Nature Reserve of Orange County, the north Irvine Ranch, the Irvine Ranch National Natural Landmark, the Irvine Ranch California Natural Landmark, Coal Canyon Ecological Reserve, Fremont Canyon, Cleveland National Forest ("Protected Lands"); and

The Protected Lands are currently owned by TIC, CDFG, and USFS, with eventual dedication of TIC lands to OCP, and have been permanently protected under various authorities including the Orange County's Central and Coastal Natural Community Conservation Plan (the "NCCP"), NROC, private conservation easements, mitigation agreements, and deed-restricted public land; and

Representatives of TIC, CDFG, USFWS, USFS, IRC, TNC and NROC have met to discuss their mutual interest in coordinating and collaborating on management and conservation of Tecate cypress. The Tecate Cypress Management Committee (TCMC) was formed with representatives of each of these agencies in order to coordinate and develop monitoring and management actions to protect this species in the Santa Ana Mountains. To facilitate the achievement of these objectives, the parties wish to document certain understandings and commitments regarding coordination and management of the conservation of Tecate cypress on the Protected Lands.

<u>**Understandings**</u>:

1) **General** – the following general understandings are observed by all the parties to this MOU.
   a. A shared commitment to protecting and managing the Tecate cypress to promote long-term persistence in the Santa Ana Mountains
   b. Participation in the TCMC in order to coordinate monitoring and management actions and to collaborate on projects to monitor, restore, and manage Tecate cypress populations in the NCCP

2) **Specific Understandings and Obligations of Individual Parties –** the following understandings and commitments are specific to various parties to this MOU.
   a. TIC as an owner of lands with Tecate cypress stands will participate as a partner in the TCMC to support monitoring and management activities to protect this species over the long-term.
   b. OCP as a future owner of lands with Tecate cypress stands will participate as a partner in the TCMC to support monitoring and management activities to protect this species over the long-term.
   c. CDFG as an owner of lands with Tecate cypress stands and as a regulatory agency overseeing the implementation of the NCCP will participate as a partner in the TCMC to support monitoring and management activities to protect this species over the long-term.
   d. USFS as an owner of lands with Tecate cypress will participate as a partner in the TCMC to support monitoring and management activities to protect this species over the long-term.
   e. USFWS as a regulatory agency overseeing implementation of the NCCP will participate as a partner in the TCMC to support monitoring and management activities to protect this species over the long-term.
   f. IRC as the designated land manager for TIC will participate as a partner in the TCMC to support monitoring and management activities to protect this species over the long-term.
   g. TNC as the designated conservation easement holder of lands recently supporting Tecate cypress will participate as a partner in the TCMC to support monitoring and management activities to protect this species over the long-term.
   h. NROC as the entity responsible for overseeing monitoring and management activities in the NCCP will participate as a partner in the TCMC to support monitoring and management activities to protect this species over the long-term.

3). **Process for Amendment** - This MOU may require amending from time to time during implementation. All amendments must be executed in writing by the initial signatories below or their equivalent replacements.

4). **Termination -** This MOU shall become operational and effective upon execution by all parties. It shall remain in force and effect regardless of ownership of the Protected Lands. This MOU shall remain in effect until termination by all parties. It is further agreed that any party may terminate its individual participation in the MOU by giving written notice to the other parties at least ninety days (90) prior to the date of termination.

5). **Insurance and Liability -** Notwithstanding the provisions of Government Code 895.2, each party shall defend, indemnify, and hold harmless the other parties and their officers, agents, employees and representatives from any and all losses, liability, damages, claims, suits, actions and administrative proceedings, and demands and all expenditures and cost relating to acts or omissions of the indemnitor, its officers, agents or employees arising out of or incidental to the performance of any of the provisions of this MOU. No party assumes liability for the acts or omissions of persons other than each party's respective officers, agents or employees.

By entering this MOU, no party waives any of the immunities provided by the Government Code or other applicable provisions of law. This MOU is not intended to confer any legal rights or benefits on any person or entity other than the parties of this MOU nor to extend rights or obligations to any party beyond the terms and scope of this MOU.

Executed on this ___ day of ________, 2010.

ORGANIZATION

By: ____________________________

Title: ___________________________

ORGANIZATION

By: ______________________________

Title: ______________________________

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10.0 APPENDICES

Table A.1 Vegetation types found throughout the study area. Codes correspond to nomenclature associated with LANDFIRE layers. The existing vegetation type data layer represents the current distribution of the terrestrial ecological systems classification developed by Nature Serve for the western Hemisphere. Vegetation types are mapped in LANDFIRE using decision tree models, field reference data, Landsat imagery, digital elevation model data, and biophysical gradient data (LANDFIRE).

Variable Code	Description
11	None
12	Open Water
20	Snow/Ice
21	Developed-General
22	Developed-Open Space
23	Developed-Low Intensity
24	Developed-Medium Intensity
31	Developed-High Intensity
32	Barren
80	Quarries/Strip Mines/Gravel Pits
81	Agriculture-General
82	Agriculture-Pasture/Hay
2002	Inter-Mountain Basins Sparsely Vegetated Systems
2014	Western Great Plains Dry Bur Oak Forest and Woodland
2019	East Cascades Mesic Montane Mixed-Conifer Forest and Woodland
2027	Madrean Upper Montane Conifer-Oak Forest and Woodland
2029	Mediterranean California Mesic Mixed Conifer Forest and Woodland
2082	Inter-Mountain Basins Mixed Salt Desert Scrub
2092	Sonoran Mid-Elevation Desert Scrub
2096	Apacherian-Chihuahuan Mesquite Upland Scrub
2097	California Maritime Chaparral
2098	California Mesic Chaparral
2099	California Montane Woodland and Chaparral
2105	Mogollon Chaparral
2108	Rocky Mountain Gambel Oak-Mixed Montane Shrubland
2110	Sonoran Paloverde-Mixed Cacti Desert Scrub
2112	Western Great Plains Mesquite Woodland and Shrubland
2113	California Central Valley Mixed Oak Savanna
2118	Southern Rocky Mountain Ponderosa Pine Savanna
2129	Northern California Coastal Scrub
2152	California Central Valley Riparian Woodland and Shrubland
2155	Inter-Mountain Basins Montane Riparian Systems
2181	Introduced Riparian Vegetation
2182	Introduced Upland Vegetation-Annual Grassland
2183	Introduced Upland Vegetation-Perennial Grassland and Forbland
2184	Introduced Upland Vegetation-Annual and Biennial Forbland
-9999	No Data

Table A.2. Nomenclature for functional groups. We used vegetation coverage classes provided on the original LANDFIRE raster layer to reclassify vegetation by functional groups. Values on the description column correspond to original LANDFIRE classes.

Variable code	Description
0	Correspond to developed areas, crops, or open water (LANDFIRE codes 11,22,31,82 from Table A.1)
1	Herb. Vegetation coverage numbers between 101 and 109
2	Shrub. Vegetation coverage numbers between 110 and 119
3	Tree. Vegetation coverage numbers between 120 and 129
4	Sparse vegetation. Vegetation coverage numbers 100

Table A.3. Vegetation coverage values. We used the midpoint percentage coverage from interval reported on LANDFIRE layers. In LANDFIRE vegetation coverage is generated separately for tree, shrub and herbaceous cover life forms using training data and a series of geospatial data layers. Percentage tree canopy cover training data are generated using digital orthophotographs and/or high spatial resolution satellite data for multiple sites. Percentage shrub and herbaceous canopy cover training data are generated using plot-level ground-based visual assessments. We remove the distinction between trees, shrubs, and herbs during our manipulations.

Cell Value	**Range of coverage**
0	Correspond to developed areas, crops, or open water (LANDFIRE codes 11,22,31,82 from Table A.1)
1	Sparse vegetation (LANDFIRE code 100)
5	< 10%
15	10-20%
25	20-30%
35	30-40%
45	40-50%
55	50-60%
65	60-70%
75	70-80%
100	80-90%

Table A.4. **Average vegetation height values**. We used the midpoint average height from the intervals reported on LANDFIRE layers. Height is reported in centimeters. In LANDFIRE canopy height is generated separately for tree, shrub and herbaceous cover life forms using training data and a series of geospatial data layers. Vegetation height is determined by the average height weighted by species cover and based on existing vegetation type life-form assignments. Dominant life-form height of each plot is then binned as follows: (A) Tree classes; 0-5 m, 5-10 m, 10-25 m, 25-50 m, and greater than 50 m, (B) Shrub classes; 0-0.5 m, 0.5-1.0 m, 1.0-3.0 m, greater than 3.0 m, (C) Herbaceous vegetation classes; 0-0.5 m; 0.5-1.0 m, greater than 1 m.

Cell Value	Range of vegetation height
0	Correspond to developed areas, crops, or open water (LANDFIRE codes 11,22,31,82 from Table A.1
10	Sparse vegetation (LANDFIRE code 100)
25	0-0.5m
50	0.5-1m
100	herb >1 m
250	herbs 1m-3m or shrubs 0-5m
300	shrub > 3m
750	5-10m
1250	10-25m
1750	25-50m

Table A.5. Correlation matrix of environmental variables used in modeling Tecate cypress habitat suitability. Highlighted values correspond to correlations greater than 0.5. AWC refers to available water content; DTRL is depth to any restrictive layer; ORGMAT is percentage of organic matter; ELEVT is elevation; VFUNCG is vegetation functional groups; VCOV is vegetation coverage; VHEIGHT is vegetation height; Vtype is Vegetation type; AVNGT and AVGST are average temperature during non-growing and growing season months, respectively; MAXGST, MAXNGST, refer to maximum temperature during growing and non-growing season, respectively; MINGST, MINNGST refer to minimum temperatures during growing and non-growing season months. TGSP is total growing season precipitation. Refer to table 2 for full variable descriptions.

	AWC	% Clay	DTRL	ORGMAT	pH	%Sand	Elevt	VFUNCG	SLOPE	VCOV	VHEIGHT	Vtype	ASPECT	AVNGT	AVGST	MAXGST	MAXNGST	MINGST	MINNGST	TGSP
Clay	0.185																			
DTRL	-0.738	0.397																		
ORGMAT	0.367	0.533	0.134																	
PH	0.633	0.639	-0.154	0.437																
Sand	0.31	-0.771	-0.662	-0.216	-0.063															
Elevt	-0.127	0.169	0.228	0.192	-0.035	-0.198														
VFUNCG	0.087	0.192	-0.067	-0.009	0.107	-0.141	-0.012													
SLOPE	0.217	-0.162	-0.31	-0.144	0.089	0.266	-0.149	-0.054												
VCOV	-0.058	-0.228	0.027	-0.049	-0.121	0.154	-0.435	-0.71	0.041											
VHEIGHT	0.088	0.126	-0.066	0.007	0.08	-0.089	-0.101	0.739	-0.081	-0.431										
Vtype	0.016	0.159	0.033	0.03	0.077	-0.14	-0.061	0.288	0.023	-0.275	0.193									
CANHGHT	0.09	0.109	-0.092	-0.028	0.079	-0.07	-0.079	0.761	-0.073	-0.489	0.944	0.221								
ASPECT	0.02	0.218	0.067	0.121	0.107	-0.167	0.125	0.102	-0.251	-0.195	0.272	0.039								
AVNGT	0.072	-0.087	-0.067	-0.054	0.094	0.167	-0.796	-0.05	0.11	0.438	0.011	0.062	-0.241							
AVGST	0.106	-0.116	-0.338	-0.283	-0.05	0.016	-0.442	0.127	0.182	0.017	0.093	0.054	0.094	0.124						
MAXGST	0.032	0.182	-0.025	0.051	0.037	-0.221	0.666	0.102	0.059	-0.434	0.008	0.017	0.254	-0.701	0.309					
MAXNGST	0.013	0.219	0.156	0.211	0.174	-0.098	0.223	0.014	0.123	-0.081	0.003	0.083	-0.065	0.327	-0.343	0.075				
MINGST	0.072	-0.148	-0.365	-0.329	-0.107	0.026	-0.357	0.191	0.182	-0.087	0.159	0.058	0.115	-0.012	0.965	0.345	-0.413			
MINNGST	0.133	-0.164	-0.266	-0.187	0.004	0.159	-0.931	0.044	0.15	0.336	0.081	0.082	-0.1	0.767	0.62	-0.499	-0.164	0.529		
TGSP	-0.089	0.184	0.28	0.291	0.024	-0.145	0.91	-0.06	-0.169	-0.287	-0.106	-0.074	0.052	-0.587	-0.67	0.446	0.398	-0.616	-0.943	
TNGSP	-0.072	0.233	0.26	0.246	0.089	-0.213	0.872	-0.069	-0.068	-0.249	-0.056	-0.074	0.135	-0.649	-0.519	0.575	0.327	-0.484	-0.92	0.908

Appendix 1

A comparative review of life history characteristics and conservation status of Cypress species in California

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I. Introduction

The genus *Cupressus* includes species distributed in the new world, most of them with relatively narrow geographic distribution or small and scattered populations. This trend is particularly dramatic in most species present in California, including the Tecate cypress (*Cupressus forbesii*). Distribution of Tecate cypress is limited to five populations in southern California, and several small scattered stands along Baja California, Mexico (Little, 2005). Given that this species is locally restricted and exists in relatively small numbers of individuals per stand, state and local agencies in California have increased their level of concern on the conservation status of this species, especially with current changes in environmental conditions. Particularly worrisome is the trend of increased fire frequency that threatens the persistence of Tecate populations. Frequent fires prevent individuals from reaching a reproductive stage that guaranties recruitment after fire (Dunn 1986).

Despite the clear sensitivity of Tecate populations to fire frequency, little information is available about potential factors that can contribute to the restricted distribution of this species. The objective of this review is to explore the role that life history characteristics might have on the current conservation status of the Tecate cypress in California. In particular, we evaluate support for two possible explanations regarding current restricted population distribution. One explanation is that the current distribution of Tecate cypress is a consequence of restricted tolerance of this species to warm and dry environments. Paleobotanical records suggest that past distribution of this species was broader (Axelrod, 1996) and the current distribution reflects the inability of this species to cope with increasingly dry and warm climates. Further climate change will put the species more and more at risk inthis scenario. Alternatively, the current distribution of Tecate cypress is a consequence of poor competitive ability. Although this species may be tolerant to a range of environmental conditions (Wolf, 1948; Zeddler et al., 1984), its current distribution reflects its poor competitive ability during inter-fires periods. This competition limits population expansion or recovery in the presence of fast-growing native and exotic competitors.

Management of Tecate population will be strongly depent on which explanation is more probable. Under the explanation that current distribution of Tecate cypress reflect the inability of the species to cope with changes in environmental conditions, management strategies should devot efforts on exploring new locations with appropriate environmental conditions. On the other hand, should the poor competitor hypothesis be more probable, management of Tecate population should concentrate on strategies that guaranty recruitment within current population stands.

Here, we compile ecological information about Tecate cypress and other related species to test possible correlations between specific life history traits and current abundance of each species in its native range of distribution, and its conservation status. We focus the review on all *Cupressus* species present in California, and several other species present in southwestern U.S., Mexico, and Central America (Table 1). We include historical and contemporary documentation on species relationships, past and present distribution, and life history traits for all species, with particular attention to the quality of the information. Throughout this document we make a clear distinction between anecdotal information and sources that provide core data as a result of observational or experimental studies. Our ultimate plan is to connect this information to possible manangement approaches.

Table 1. Included *Cupressus* species. Species of *Cupressus* included in this review and present in California, Mexico, and Central America. Table indicates current conservation IUCN status and the species at risk due to small population size.

Genus	Species	subspecies	Common Name	Occurrency (Wolf, 1948; Armstrong, 1966; Johnson, 1970; Griffith and Critchfield, 1972)	IUCN status (IUCN, 2009)	Risk (IUCN, 2009)
Cupressus	*forbesii*		Tecate cypress	San Diego Co., California, & Baja California, Mexico	Vulnerable	Population is very small/restricted distribution
Cupressus	*guadalupensis*		Guadalupe cypress	Mexico, Guadalupe Island	Critically Endangered	Severely Fragmented/Continuing decline
Cupressus	*goveniana*	*abramsiana*	Santa Cruz Cypress	California: Santa Cruz & San Mateo Co.	Vulnerable	Population<10000/Severely Fragmented/Continuing decline
Cupressus	*goveniana*	*goveniana*	Gowen cypress	California coast from Mendocino Co. to San Diego Co.	Vulnerable	Population<10000/Severely Fragmented/Continuing decline
Cupressus	*Goveniana*	*pygmaea*	Mendocino cypress	California coast in Mendocino Co.	Vulnerable	
Cupressus	*sargentii*		Sargent cypress	California, in the coast range in scattered stands from Mendocino Co. S to Santa Barbara Co.	Lower Risk/least concern	
Cupressus	*bakeri*		Modoc cypress	California & Oregon in Siskiyou Mtns & NE California	Vulnerable	Severely Fragmented/Continuing decline
Cupressus	*macrocarpa*		Monterrey cypress	Central California coast in Monterey Co. between Monterey & Carmel Bays; scattered on inland ridges	Vulnerable	Population is very small/restricted distribution
Cupressus	*lusitanica*	*lusitanica*	Mexican cypress	Central Mexico, S to Guatemala & Costa Rica	Lower Risk/least concern	
Cupressus	*lusitanica*	*benthamii*			Lower Risk/least concern	

Genus	Species	subspecies	Common Name	Occurrency (Wolf, 1948; Armstrong, 1966; Johnson, 1970; Griffith and Critchfield, 1972)	IUCN status (IUCN, 2009)	Risk (IUCN, 2009)
Cupressus	*macnabiana*		MacNab cypress	N California: Sierra Nevada foothills & interior coast range from Siskiyou to Napa Co.	Lower Risk/least concern	
Cupressus	*arizonica*		Arizona Cypress	Small, scattered areas in mtns of Arizona, New Mexico, S Texas, & N Mexico	Lower Risk	
Cupressus	*arizonica*	*stephensonii*	Cuyamaca cypress	California, San Diego Co., Cuyamaca Mtns. Sierra Juares, Baja California Norte, Mexico	Vulnerable	Population is very small/restricted distribution
Cupressus	*arizonica*	*nevadensis*	Piute cypress	California, Kern Co., Piute Mtns	Vulnerabl	Population is very small/restricted distribution
Cupressus	*arizonica*	*montana*	San Pedro Martyr cypresss		Vulnerable	Population is very small/restricted distribution
Cupressus	*arizonica*	*glabra*	Smooth arizona cypress	Mtn areas of central Arizona	Lower Risk	
Cupressus	*nootkatensis*			Pacific Coast area from S and SE Alaska through British Columbia, Washington and Oregon to extreme NW California (Earle, 2009)	Lower Risk/least concern	

II Current status of California cypresses

Origin and taxonomy of California cypresses

The family *Cupressaceae* has been divided into seven subfamilies, among which Cuppressoideae is the largest and most diverse with 11 genera and approximately 115 species (Gadek et al., 2000). Trees of this taxon are widely distributed around the world, growing in a great variety of arid and mesic environments (Little, 2006). *Cupressus* is the second largest genus within this subfamiliy, after *Juniperus*, with 28 taxa.

Species within this genus are usually grouped by their geographic distribution into Old World and New World species (Little, 2006). Recent revisions suggest the genus is not monophyletic although the two major groups of old world and new world species are consistently recognized. The monophyletic clade that includes all *Cupressus* species also includes *Juniperus* and *Callitropsis* (Little et al., 2004; Xang and Li, 2005). In a recent revision of morphological, anatomical, chemical, and molecular data, Little (2006) confirmed that *Cupressus* is not supported as a monophyletic group without *Callitropsis* and *Juniperus*. With this dataset, new world and old world taxa form distinctive groups based on a combination of morphological characters that include tree architecture (e.g. arrangement of branch segments, stem crossectional shape) and dispersal traits (serotony and cone abscission upon maturity). Even more recently, Adams et al (2009) based on molecular traits, concluded that new world *Cupressus* species are clearly distant from old world *Cupressus*, to the point that they suggest a new monophyletic genus (*Hesperocyparis*) that group Western emispher Cupressus species and excludes *Callitropsis* and *Juniperus*.

Paleobotanical evidence suggests diversification of California cypresses responded to climatic changes that fragmented a widely distributed common ancestor (Little, 1950; Twisselmann, 1962; McMillan 1952; Langenheim and Durham 1963; Spenger, 1985; Axelrod 1988). Axelrod has found several fossils of close-cone species (*Pinus radiata*, *P. muricata*) in coastal California, including parts of *C. goveniana* and *C. macrocarpa* (Axelrod, 1996). These records were in Pleistocenic deposits dated to approximately 1 million years. This collection of fossil records suggests that close-cone pine forest were wider distributed from norther Marin County to northern Baja California (Axelrod, 1996). Similarly, a fossil found in terciary deposits in the Mojave deserts (*Cupressus mohavensis*), and a fossilized cone of cypress of about 6.5 million years and similar to Tecate cypress (*Cupressus pre-forbesii*) suggest an even older and wider distribution of a common ancestor (Spenger, 1985). Systematic studies are congruent with this interpretation as New World species consistently form a monophyletic group, especially species of *Cupressus* found in southwestern U.S, Mexico, and Central America (Bartel et al., 2003; Little, 2006).

Systematic studies have found commonalities among New World cypress species that justify considering them within a consolidated group. Following the taxonomic key provided by Little (2006) the genus *Cupressus* can be characterized as single stemmed trees of caespitose shrubs that may produce two different type of leaves once matured, and have terminal branches arrange in two planes. Seeds of these species are flatted in cross section, irregularly shaped, with wings that could be reduced. They develop two cotyledons and a fibrous bark. In particular, similarities among new world *Cupressus* species revolve around branch and leaves arrangements, time of dispersal and cone abscission. Little (2006) suggests that these characteristics arise as adaptation to arid environments, when compared to Old world species. Nevertheless, when only new world species are considered, ecological descriptions emphasize the low tolerance of these trees to arid conditions. In fact, some authors have suggested the confinement of some cypresses to canyons and ravines result from the low tolerance of these species to dry conditions (Wolf, 1948; Armstrong, 1966 and 1978; Griffith and Critchfield, 1972; Vogl and Armstrong 1988; Rehfeldt et al., 2003; Minnich, 2007).

In addition to morphological characteristics, current species descriptions suggest similar life cycles, although this similarity reflects a great deal of uncertainty about specific life cycle events for most of the species. In all species staminated cones are produced at younger ages than ovulated cones, and once pollination occurs, seed maturation takes between one and two years (Wolf, 1948; Fargon 2005). Seedlings tend to establish in bare soil, and even in areas with very poor nutrient levels (Wolf, 1948; Armstrong, 1966 and 1970; Vogl et al., 1988; Fargon, 2005; Minnich, 2007). Most species are reported to be very plastic in that under unfavorable conditions trees grow stunted, but are able to produce cones; under more favorable conditions, trees of the same species grow taller and more vigorously (Wolf, 1948).

Within this group of New World species, taxonomical differences revolve around specific characteristics of habit, bark, leaves, and cones (Wolf 1948). Most species develop a central leader, especially *C. sargentii*, *C. bakeri*, *C. arizonica*; although this is not the case for *C. guadalupensis* and Tecate cypress. Bark can be fibrous gray or dark brown and split in longitudinal strips (*C. macrocarpa*, *C. pymaea*, *C. sargentii*), which is associated with higher fire-resistance. Other species have thinner, non-fibrous, exfoliating bark, which offers little fire protection (*C. glabra*, *C. forbesii, C. guadalupensis*, *C. stephensonii*). Branches can be clearly pendulus (*C. lusitanica*, *C. benthamii*) and branchelets are characteristically arranged in one plane in *C. macnabiana*. In some species, leaves have glands that produce a clear resin that turns gray when dry (*C. glabra* and *C. nevadensis*, *C. stephensonii*, *C. arizonica*, *C. montana*, *C. macnabiana*, *C. bakeri*). Although the aforementioned traits separate subgroups, and even species, most species are distinguished by subtle differences in foliage coloration and size and number of scales in the ovulated cones.

Despite morphological differences, systematic analyses do not confidently resolve species relationships and do not support intraspecies groups based only on morphological and genetic variation. These discrepancies include classifying *C. arizonia, C. glabra, C. montana, C. nevadensis,* and *C. stephensonii* as subspecies of *Cupressus arizonica* (Rehfeldt, 1997; Bartel et al., 2003); *C. benthamii* as a close relative of *C. lusitanica* (Farjon, 1998 and 2005) without including *C. Montana*; and Tecate cypress as close relative to *C. guadalupensis* without including *C. stephensonii* (Little, 1970; Farjon, 1998). Little (2006) suggests a change in nomenclature that implies restricting *Cupressus* to the old world, recognizing *Juniperus*, and expanding *Callitropsis* to include all new world species along with *Callitropsis nootkatensis* and *Callitropsis vietnamensis*.

The position of Tecate cypress within the group of new world species has not been properly resolved. Wolf (1948) recognized Tecate cypress as a distinctive species from *C. guadalupensis* given that Tecate cypress has bright light green foliage and 12-14 scales on the staminated cone while *C. guadalupensis* has bluish-green or more glaucous foliage and cones with as many as 18 scales. Little (1970) proposed Tecate cypress to be a subspecies of *C. guadalupensis*, and this grouping remained in latter classifications (Eckenwalder 1993; Farjon 1998). Using random applified polymorphic DNA sequences Bartel (2003) found Tecate cypress to be highly variable, but closely related to, but distinctive from *C. guadalupensis*, *C. macrocarpa*, *Callitropsis nootkantensis*, and *C. bakeri*. Finally Little (2006) using a more comprehensive dataset reported *C. guadalupensis* as closely related with *C. stephensonii*, and both taxa closely related with Tecate cypress. These three taxa form a monophyletic group with *C. arizonica*, and *C. glabra*.

Rosas-Escobar et al. (2008) used chloroplastic DNA (cpDNA) markers to assess the genetic variability in the population of *C. guadalupensis* and its relashionship with its closest relative, Tecate cypress. The authors found 13 unique haplotypes: one that showed high frequency and is shared with all Tecate cypress populations, and three more that are shared with some Tecate cypress populations. Given that recent genetic flow among populations seems unlikely due to geographic barriers, shared haplotypes suggest the existence of a more widely distributed common ancestor following the last glacial maximum. Similarly, populations of Tecate cypress showed 4 unique haplotypes and genetic diversity which decreases with latitude; northern populations were more genetically diverse. Contrary to expectations, genetic diversity of Tecate cypress is lower than *C. guadalupensis* despite the fact that Tecate cypress has more populations and its distribution is regionally less restricted. Authors suggest this reflects the restrictive connectivity and smaller size of Tecate cypress populations.

Using several traits measured in seedlings grown for three years, Rehfeldt (1997) found a clear separation between the *C. arizona* group (*C. stephensonii, montana, nevadensis, glabra, and arizonica*) and both Tecate cypress and *C. glabra.* Both Tecate cypress and *C. glabra* showed high growth potential, late cessation of shoot elongation, low freezing tolerance, and poor survival and large stress response in mountain conditions. Rehfeldt (1997) interpreted these results as evidence of the adaptation of these species to milder climate along the California coast, which contrast with the harsher mountain environments occupied by species from the *C. arizonica* group. Nevertheless, this study suggests a closer relation between *C. nevadensis* and *C. glabra* than suggested by Little (2006) and Bartle et al. (2003). Rehfeldt (1997) further suggested that restricted distribution of both *C. nevadensis* and *C. glabra* might reflect the lack of genetic variability appropriate for adjusting to different conditions. This suggestions support the hypthesis that current restricted distribution of cypresses in California reflecs the inability of the recent common ancester to cope with changes in environmental conditions.

Current distribution

In this section, we summarize the main geographic characteristics of current distribution of Californian cypresses. Table 2 presents specific values for the most important geographic traits at the range of distribution for each species.

Cupressus forbesii and *C. guadalupensis* are usually described as closely related species, and some authors even consider Tecate cypress a variety of *C. guadalupensis* (Little 1970; Farjon, 1998 and 2005). Recent studies treat them as separate species on the basis of morphological, chemical, and molecular differences (Bartel, 2003; Little, 2006). *Cupressus guadalupensis* is restricted to the Guadalupe Islands, Mexico (De la Luz et al., 2005). Very few species grow within stands of *C. guadalupensis*, but *Quercus tomentella, Ceanonthus insularis,* and *Rhamnus pirifolia* are common in adjacent areas (Minnich, 2007). Contrary to *C. guadalupensis, Cupressus forbesii* is distributed in four scattered groves in southern California and several disjunct stands in northern Baja California between 200-1200 masl. In California, it occurs in the Santa Ana Mountains, Orange County; in San Diego County it occurs in Guatay

Mountain, Otay Mountain, and Mount Tecate (Table 2). Along this range of distribution, Tecate cypress is associated with Chaparral vegetation. In San Diego County, this species grows on poor but moist soils higher in elevation with *Pinus coulteri* and *P. Jeffreyi* (Zedler, 1981). This characteristic distribution of small scatter populations make management of this species particularly challenging given that efficient strategies will first have to identify commonalities among disjunt population and particular conditions at each separate population that guaranty species persistence.

Similar to the restricted and scattered distribution of Tecate cypress, most Californian cypresses are distributed throughout small geographic areas with scattered populations that usually form monocultures. This restricted and fragmented distribution justifies the current concervation status of several of the Californian Cypresses (Table 1).

Several species are distributed close to the coastal line and at elevations lower than 2000 masl (Table 2). A notable exception is *C bakeri* that has the northern most populations and occurs at the highest elevation in California. This species rarely form pure stands (Wolf, 1948) and is associated with, northern juniper woodland, yellow pine forest, and sagebrush scrub (Esser, 1994). In contrast to *C. bakeri*, the complex of C. arizonica that includes five species (*C. arizonica, C. glabra, C. montana, C. nevadensis, and C. stephensonii)* occurs in southern California and at lower elevations (Table 2). Wolf (1948) recognized the five species within the complex, while Little (1970) and Fargon (1998) treat them all as varieties of *C. arizonica.* Out of these five taxa only two occur in California (*C. stephensonii* and *C. nevadensis*). *Cupressus nevadensis* is restricted to the Piute Mountains in the vicinity of Kern and Tulare counties and it is commonly associated with *Juniperus californica, Pinus sabiniana, P. monophylla* and *Ephedra viridis* (Abrams 1919). It is commonly planted in the region and in southern California; in some of these areas it may be naturalized (Wolf, 1948). *Cupressus stephensonii* is the rarest of named cypresses being restricted to the southwest side of Cuyamaca Peak, San Diego County (Peattie 1950) and east of Santa Catarina in Sierra Juarez, Baja California, Mexico (Vogl et al., 1977). In California, this species grows in association with chaparral vegetation where *Pinus coulteri* also occurs (Vogl et al., 1977). The other species related with *C. arizonica* grow in southern states (Texas, New Mexico, Arizona) and in northern Mexico like *C. montana* and *C. arizonica* (Table 2).

Other cypresses are distributed close to the coast of California like the taxa related with *C. goveniana* (*C. goveniana,* C. *pygmaea,* and *C. abramsiana),* which are currently treated as separate varieties (Fargon. 1998). *C. goveniana* is restricted to two populations in the Monterey peninsula (Griffin and Critchfield, 1972; Vogl and Armstrong, 1988) where it usually associates with *Pinus muricata. C. pygmaea* grows in Mendocino County with populations scattered 2.4-3.2 km inland (Griffin and Critchfield, 1972) an growing in association with *Sequoia sempervirens* and *Pseudotsuga menziesii. C abramsiana* is restricted to four groves in Santa Cruz and San Mateo Counties (Vogl and Armstrong, 1988, Lyons, 1998). Along its range, this species associates with chaparral (Wolf, 1948) but some groves contain *Pinus attenuata* and *Pinus ponderosa* (Lyons, 1998). Finally, *Cupressus macrocarpa* is restricted to two populations on the Monterrey Peninsula (Posey and Goggans, 1967 Vogl and Armstrong, 1988), where it grows along with closed-cone coniferous woodlands and closed-cone pine-cypress forests (Vogl et al., 1977). It mixes with northern coastal bluff scrub on exposed seaward edges and with *Pinus radiate* forest away from the ocean (Esser, 1994). This species has been widely planted along the California coast, and some of these plantations have become naturalized (Griffin and Critchfield, 1972; Holland, 1986).

The species that are not considered vulnerable (Table 1) have populations distributed along a wider geographical area, or are locally abundant. Within the cypresses occurring in

California, *C. macnabiana* and *C. sargentii* are the most widely distributed and abundant. *Cupressus macnabiana* is the most widely distributed cypress with numerous scatter groves in the inner northern Coastal Ranges up to Amador County. This species occurs in areas of the Upper Sonoma Life Zone (Wolf, 1948). In drier areas, *C. macnabiana* grows along with chaparral and foothill woodland species; *Pinus sabiniana Pinus attenuata* are common within groves of this species (Wolf, 1948; Vogl et al., 1977). In some areas, *C. macnabiana* ocurrs sympatrically with *C. sargentii,* although at higher slopes (McMillan, 1956; Vogl et al., 1977). *C. sargentii* is the second widest distributed species and is locally abundant along 400 miles on the Coastal Ranges (Griffith and Critchfield, 1972). It is associated with serpentine chaparral, upper Sonoran mixed chaparral, montane chaparral, or knobcone pine forest communities, and mixed evergreen forest or montane coniferous forest (Kruckerber,1984; Holland, 1986; Esser, 1994). *C. sargentii* occurs sympatrically with *C. macnabiana* in Lake County, where it is larger and tends to occupy lower slopes than *C. macnabiana* (McMillan, 1956; Vogl et al., 1977).

Similarly to *C. sargentii* and *C. macnabiana* in California, not threaten cypress species outside California are wider distributed and abundant thoughout their range. *Cupressus lusitanica* and *C. benthamii* are well distributed in Mexico. *C. lusitanica* also grows in Central America (El Salvador, Guatemala, Honduras, and Belize). *C. lusitanica* often form pure stands and it is commonly associated with *Pinus* species (Farjon 2005). *C. benthamii* grows sympatrically with *C. lusitanica* at elevations of 1500-3990 m (Farjon 2005), and it is locally aboundant thoughout its range.

Table 2. Geographic features at the range of distribution of selected *Cupressus* species.

Species Name	Common Name	Number of Groves (at least otherwise specified from Griffith and Critchfield, 1972)	Latitud (ºN – Bannister, 1980)	Distance from the Sea (km- Bannister, 1980)	Elevation (m.a.s.l. – Freom Earle, 2009)	Annual raifall in cm (cm/year- at least otherwise specified from Posey and Goggans,)	Aspect (at least otherwise specified Posey and Goggans,)
C. forbesii	Tecate cypress	5+	32-33 (excluding Baja California populations)	16-64	200-1200	45.72-50.8	North-NorthWest
C. guadalupensis	Guadalupe cypress	1	29	1.6-3.2	950-1300	12.00-20.00 (Rogers, 2002)	Northwest (Rogers, 2002)
C. goveniana							
C. goveniana var. abramsiana	Santa Cruz Cypress	3	37	6.4-19.2	300-760		
C. goveniana var. goveniana	Gowen cypress	2	36-37	1.6-4.8	30-300	71.12-152.4	West, South West
C. goveniana var. pygmaea	Mendocino cypress	3	39	1.6-4.8	<500	91.44-101.6	Plateau
C. sargentii	Sargent cypress	19+	35-40	4.8-96	200-1100	76.2-86.26	Southwest
C. bakeri	Modoc cypress	6	40-42	72-224	1150-2150	60-96-71.12	North
C. macrocarpa	Monterrey cypress	2	36	0	0-30	71.12-81.28	West
C. lusitanica var. lusitanica	Mexican cypress	many (Bannister, 1980)	10-29	48-640	1500-3990		
C. lusitanica var. benthamii		1 (Bannister, 1980)	20	80-160	1500-3990		
C. macnabiana	MacNab cypress	15+	38-41	40-200	300-850	76.2-86.26	Ridgetop and Northeast
C. arizonica	Arizona Cypress	13	24-33	11.2-640	1000-2200	40.64-60.96 cm	All slopes

Species Name	Common Name	Number of Groves (at least otherwise	Latitud (ºN – Bannister, 1980)	Distance from the Sea (km-	Elevation (m.a.s.l. –	Annual raifall in cm (cm/year- at least	Aspect (at least otherwise

		specified from Griffith and Critchfield, 1972)		Bannister, 1980)	Freom Earle, 2009)	otherwise specified from Posey and Goggans,)	specified Posey and Goggans,)
C. arizonica var. stephensonii	Cuyamaca cypress	1	32	56	900-1200	76.2-86.26	Southwest
C. arizonica var. nevadensis	Piute cypress	2	36	160	1200-1800		Northeast
C. arizonica var. montana	Monterrey cypress	1	31	32-40	2300-2825		
C. arizonica var. glabra	Smooth arizona cypress	7	34-35	352	1200-1680	40.64-60.96 cm	Ravine
C. nootkatensis		many (Bannister, 1980)	44-61	0-720	762-2280		

Environmental controls on species distribution

In addition to the paleobotanical studies that suggest a wider historical distribution for California cypresses, other studies based on current range of distribution support the hypothesis that *Cupressus* species do not tolerate warm and dry climates (McMillan, 1956; Bannister, 1980; Zedler, 1981; Vogl and Armstrong 1988, Lyons, 1998). Nevertheless, experimental evidence regarding this explanation is scarce. Most evidence comes from the interpretation of environmental conditions at current species distributions.

Out of all considered species, *C. bakerii, C. arizonica, and C. glabra* are ones that occur in warmer and drier environments. Other species exist relatively close to the sea, which allows for moister growth conditions, or at higher elevations, which facilitates cooler and moister habitats (for example for *C. guadalupensis, C.goveniana, C. montana, and C. lusitanica*). Fog and cool temperatures generated by the marine layer provide moisture in the form of foliar fog drip condensation, which might explain the distribution of southern cypresses on western slopes in southern California and northern Baja California (Minnich, 2007). In fact, in the Santa Ana Mountains fog drip can reach 10 cm per month in late spring, favoring knob-cone pine growth at medium elevations (1000 m.a.s.l.-Vogl, 1973) and probably favoring growth of Tecate cypress. In addition, cold temperatures limit the northern distribution of California cypresses. Rehfeld (2003) experimentally demonstrated that *Cupressus* species significantly differ in their response to low temperatures. Tecate cypress showed lower resistence to cold temperature compared to *C. sargentii* and *C. nevadensis*, which Rehfeld (2003) interpreted as an adaptation of this species to coastal environments. Evidence of cold intolerance also comes from unsuccessful attempts at cultivating California cypress in areas with periods of prolonged cold in Europe (Bannister, 1980); this is the case *for C. macrocarpa, C. arizonica,* and *C. lusitanica.* In this sense, conservation strategies for the Tecate cypress should consider the restriction on potential habitat suitability imposed by topographic features. Nevertheless, considering the current trends of climate change, populations could be viable at range of elevations higher than its current range.

Table 3. Traits associated with germination and survival of seedlings for selected *Cupressus* species.

Species Name	**Common Name**	**Soundness % (Wolf, 1948**	**Germination Capacity (First number from Wolf, 1948; second is meand and standard deviation from Ceccherii, 1998)**	**Seedling tolerance to light**	**Seedling Survival on cultivation (Wolf, 1948)**	**Suceptibility to cypress Canker (Wagener, 1948)**	**Adult Resitence to fire**
C. forbesii	Tecate cypress	54	12-?	shade intolerant (Armstrong, 1966)	0.42-0.37	Slightly suceptible	Low
C. guadalupensis	Guadalupe cypress		?-45.39(32.79)		?-0.9	Not suceptible	
C. goveniana						low	
C. goveniana var. abramsiana	Santa Cruz Cypress			shade intolerant (Kuhlmman, 1986 Lyons, 1998)	0.77-0.11	qutie suceptible	
C. goveniana var. goveniana	Gowen cypress	93	22-97.50 (12.72)		0.97-?	quite suceptible	moderate
C. goveniana var. pygmaea	Mendocino cypress		31-92.42(5.00)		0.03-0.04	quite suceptible	moderate
C. sargentii	Sargent cypress	41	13-?	shade tolerant (Cheng, 2004)	0.38-0.08	Moredately suceptible	resistent
C. bakeri	Modoc cypress	36	12-?	shade intolerant (Waganer, 1963)	0.02-0.04	Not suceptible	non resistente
C. macrocarpa	Monterrey cypress	82	14 to 24-?	?	0.01-0.002	Very Suceptible	some
C. lusitanica var. lusitanica	Mexican cypress		20- 73.28 (30.81)	shade tolerant? (Wolf, 1948)		Moredately suceptible	
C. lusitanica var. benthamii				shade tolerant? (Wolf, 1948)			
C. macnabiana	MacNab cypress	5	1 to 15-?		0.01-0.006	Moredately suceptible	
C. arizonica	Arizona Cypress	30	26-?	shade-intolerant (Brown, 1982)		Not suceptible	

Species Name	**Common Name**	**Soundness % (Wolf, 1948**	**Germination Capacity (First number from Wolf, 1948; second is meand and standard deviation from Ceccherii, 1998)**	**Seedling tolerance to light**	**Seedling Survival on cultivation (Wolf, 1948)**	**Suceptibility to cypress Canker (Wagener, 1948)**	**Adult Resitence to fire**
C. arizonica var. stephensonii	Cuyamaca cypress				0.52-?	Not suceptible	non resistant
C. arizonica var. nevadensis	Piute cypress	38	6-?		0.43-0.85	Slightly suceptible	resistant
C. arizonica var. montana	San Pedro Martyr cypresss			?			
C. arizonica var. glabra	Smooth arizona cypress		?-98.68 (3.72)			Not suceptible	
C. nootkatensis				shade tolerant (Ashton, 2005)			

Life history characteristics

Past experimental studies on ecological characteristics of California cypresses have focused on four main aspects 1) soil preferences 2) germination capacity 3) susceptibility to fungi 4) seedling growth. Observational studies have explored population level consequences of fire-dependence of seed dispersal by comparing pre- and post-fire population densities (Armstrong, 1966; Armstrong and Vogl 1978; Zedler, 1981; Dunn 1985, Lyons, 1988, Neeman et al., 1999, DeGouvaine and Ansary, 2007). In the following section, we present the main findings of the four aspects that have been explored in some detail, and a summary of the current knowledge regarding population status.

Soil Preferences

New world *Cupressus* species usually grow in areas with special soil characteristics. Nevertheless, because almost all New world *Cupressus* have been grown in a variety of soil types, their restriction to soils with particular characteristic is probably a consequence of several ecological factors, not only of a narrow physiological tolerance to specific soil properties. In fact, conservation status of cupressus species does not show any correlation with species-specific restrictions to soil types (Table, 3)

McMillan (1956) explored the apparent soil restrictions of *C. macnabiana, C. sargentii, C. macroparpa, C. bakerii,* and the complex of *C. goveniana (C. abramsiana, C. pygmaea, C. goveniana).* According to McMillan (1956) *C. sargentii* and *C. macnabiana* are restricted to serpentine soils, *C. pymaea* is restricted to acidic soils. Throughout its distribution, *C. macnabiana* is found in serpentine outcroppings, in soil derived from granitic material, on gray volcanic soil north of its distribution, and on white alluvial soil south of its distribution (Wolf, 1948; McMillan, 1956). Nevertheless, seeds and seedlings from different populations of this species showed similar responses to uniform soil conditions; although germination was invariably low, seedlings grew slightly better in serpentine than in control soils. Similar results were found for *C. sargentii*; which is usually found on serpentine soils throughout its wide range of distribution (Wolf, 1948)., Despite its similarity with *C. sargentii* (McMillan, 1956) *C. abramsiana* (from the complex of *C. goveniana)* is not reported in serpentine soil, but rather on soils derived from sandstone (Vogl and Armstrong, 1977)s,. This species germinated and grew on acidic, serpentine, or control soils, although it performed better on control soils (McMilland, 1956). Despite that *C. pygmaea* is only found in very acidic soils and it is a vulnerable species (Table 1), it germinated and grew better in control soils and could tolerate serpentine soils. Similar responses were observed for *C. goveniana* and *C. marcrocarpa.* In contrast, the wider distributed *C. bakerii* responded better to sepentine soils than control soils. This species is known to occur on soils of volcanic origin and on serpentine soils (Wolf, 1948; Stone, 1965; Griffin and Critchfield, 1972). This suggests that wider distribution of this species might be a consequence of a greater proportion of appropriate soil types; for the other species other factors are probably responsible for their more restricted distribution.

Other *Cupressus* species are also associated with a specific soil type, although their soil preferences have not been experimentally tested. The group of species closely related with *C. arizonica* includes those with very restrictive distributions, such as *C. stephensonii.* The only area of occurrence for this species has a deep, stony loam soil with high water retention capacity (Cheng, 2004). In contrast, *C. nevadensis* grows in a variety of soils, including red and black clays, decomposed granite, and fractured rock, although it grows better on red clay with well-developed topsoil (Twisselman, 1962). Current information on soil characteristics in *C. montana* stands is limited to reports that patches of individuals grow in steep granite walls above 2200 m, and along arroyos at around 1400 masl (Minnich, 1987). On the other hand, *C. glabra* grows on "*north slopes entirely, and in protected watered gulches and on the sides of shallow canyon, but it occurs also on the intervening benches and ridges where the shaley soil is moist*" (extracted from species description by G. Sudworth, 1910).

Specific soil characteristics thougout the rante of distribution of *C. arizonica* indicates that this species is not restricted to a specific soi type. Parker (1980) studied environmental characteristics of several stands of *C. arizonica* in southern Arizona. In this area, *C. arizonica* grows in a variety of soils with pH around neutral, and usually good availability of water and nutrients (Parker, 1980). In particular, this species is found on sandy loam and loam soils at high and intermediate elevations (1700-2200 masl), on riparian habitats with sandy soils at lower elevations (1400-2000 masl), and on soils with high percentages of silts and clay derived from shale and limestone also at high elevation (2100-2200 masl).

Several authors coincide the restricted distribution of Tecate cypress has more to do with competition with chaparral species than narrow physiological tolerance to a particular soils type. Dunn (1986) suggests that Tecate cypress has little soil preferences given that it is found in soil derived from gabbro, granite, metavolcanic rocks, and sedimentary substrates with low fertility and high clay content. Stottlemyer and Lathrop (1981) explored in detail soil characteristics at all stands of this species in California. They found that Tecate cypress grows in a variety of soils from sandy loam to clay. They did not find evidence to the apparent soil restrictions on Tecate cypress distribution. On Tecate populations, pH ranges from 4.2 to 6.5 (mean=5.5), which tends to be slightly lower than adjacent chaparral sites where it typically ranges from 5.7 to 7.1 (Stottlemyer and Lathrop, 1981). A common denominator of soils in Tecate stands is the low levels of Nitrogen recorded (mean of 0.71 ppm for topsoil and 0.46 for subsoil). When compare with adjacent areas with big-cone Douglas Fir, Knobcone pine, mixed evergreen and oak woodlands, Stottlemyer and Lathrop (1981) concluded that Tecate can growth in soils with low nutrient levels, especially of nitrogen, phosphorus, potassium, and magnesium. In addition, they found that soils in plantations of Tecate on Sierra peak are very similar to adjacent chaparral soils. Stottlemyer and Lathrop (1981), in agreement with Armstrong (1966, and 1970, and Vogl et al., 1988), suggested that *C. forbersii* association with acidic soils result from competitive interactions with chaparral species. Thus, Tecate cypress can be considered a versatile species that can tolerate a variety of soil conditions. This characteristic will facilitate recovery strategies that depend upon ex-situ cultivations and subsequent re-introduction, even when this re-introductions are planned outside current Tecate's locations.

Germination

Studies on germination of *Cupressus* species are restricted to laboratory trials that explored the effectiveness of storage conditions or pre-germination treatments. Several authors (Rose, 1915; Barton, 1930; Johnson, 1974 Ceccherini et al, 1998) reported increased germination after stratification on *Cupressus* seeds. In a comparative study with stratified seeds, Johnson (1974) reported germination percentages between 1 and 35%, and proportion of seeds with embryos as low as 5% in *C. macnabiana* and as high as 93% in *C. goveniana* (Table 3). Ceccherini et al. (1998) explored effects of stratification on 14 *Cupressus* species, which included almost all species distributed in California, except Tecate cypress and *C. stephensonii*, but included other new and old world species such as *C. cashmeriana, C. duclouxiana, C. dupreziana, C. funebris, C. lusitanica, C. numidica,* and *C. torulosa*. Overall, these authors found a low percentage of filled seeds, 15% (s.d.=14), and an increased and faster germination rate with stratification except for *C. guadalupensis.* Interspecific differences accounted for most of the variation in germination reported in this study (41%), specifically variation on percentage of seeds with embryos. Out of the new world species *C. glabra* and *C. macrocarpa* were the only species that showed consistent improvement after cold treatment on all germination parameters. *C. arizonica* and *C. lusitanica* only showed higher speed in germination, while germination of *C. macnabiana* and *C. guadalupensis* remained low. These studies demonstrate that germination rate is highly variable among species and does not correlate well with conservation status of *Cupressus* species.

Another trait that could explain the conservation status of some *Cupressus* species is seed viability. The capacity to retain viable seeds for long periods without fire will favor population resilience after a fire event. Although Wolf (1948) reported that seeds of *Cupressus* remain viable for many years, changes in viability with age might be species specific. Magistris et al (2001) reported different patterns of germination on seeds of different ages from four *Cupressus* species (*C. arizonica, C. benthamii, C. lusitanica, C. macrocarpa*). Viability of *C. arizonica* sharply decreases with age, while for *C. lusitanica* germination remains over 15% for several seasons, and for *C. marcrocarpa* germination after 12 years remains over 5%. These authors suggest that longevity of viable seeds is favored by humidity retained in the cone and tannins that prevent seed diseases, while interspecific differences in age of maximum germination may reflect some kind of dormancy in the first four years. These findings suggest that in species with estimated optial fire regime of 35-40 years like Tecate cypress (Dunn, 1986), a sharp decrease in seed viability after 12 years will correspond with a shape decrease on potential recovery after fire. Further studies are required to assess the weight this trait has during post-fire population recruitment.

Seedlings establishment, survival, and growth

A recurrent theme in the description of habitat requirements for *Cupressus* species from California is the apparent control that soil moisture exerts on seedling survival and growth of established trees. Several authors have pointed out that moist conditions favor proliferation of pathogens given that trees grow taller and faster on moist sites (McMillan, 1956; Zedler et al., 1984; Vogl and Armstrong 1988, Lyons, 1998) which increases the risk of mechanical damage and makes them more susceptible to pathogens (McMillan, 1956). In addition, occurrence of *Cupressus* species in ravines and drainages and their preponderant distribution on north facing slopes has been interpreted as evidence of water and moisture requirements (Brown, 1982; Dunn 1986). Nevertheless, explicit exploration of this association is lacking for most of the *Cupressus* species in California. Parker (1980) explored the site preferences of *C. arizonica* and concluded that this species is not necessary restricted to moist sites. Parker suggests that this species shows ecological compensation given that it occurs along drainages and ravines on north facing slopes at low elevations and on drier microsites on south-facing slops at higher elevations that have higher mean annual precipitation.

There are very few published studies on establishment requirements and seedling survival of *Cupressus* species. Wolf (1948b) established experimental plantations of several

Cupressus species and reported survival after 9 years, as well as raw data on fertility and germination (Table 3). The groups with consistently high seedling survival in monocultures and mixture plantations were Tecate cypress, and *C. nevadensis*. Species with consistently low survival probability include *C. pygmaea*, *C. bakeri*, *C. macrocarpa*, and *C. macnabiana* (Table 3) despite the wide distribution of *C. macrocarpa*, and *C. bakeri* in the wild. In a study with *C. arizonica*, Harrington et al. (2004) found overall low seedling mortality in seedlings transplanted on sites with soil moisture and weed controls. Overall survival after 6 growing seasons was greater than 20% but less than 60% in all treated sites and between 10 and 20% in controls. After the first growing season, mortality for *C. arizonica* in treated sites was relatively low (11-15%). This study suggests that proper control on soil moisture conditions will favor seedling survival in natural conditions.

In addition to low tolerance to dry conditions, some *Cupressus* seedlings are not resistant to cold temperatures. In a common garden experiment Rehfeldt (2003) evaluated 16 seedling traits for *C. arizonica, C. montana, C. nevadensis, C. sargentii, C. forbesii, C. glabra,* and *C. stephensonii* and found significant interspecific differences in almost all traits. Discriminant analysis clearly separated Tecate cypress and *C. sargentii* from the other species, as well as *C. arizonica* from these two species and from other species in general. Authors interpreted these separations as a consequence of adaptation of Tecate cypress and *C. glabra* to mild climate along the pacific coast, and of *C. arizonica* to harsher montane conditions. The ordination was driven mostly by low survival and large response to stress in Tecate cypress and *C. sargentii*. The authors also found strong intraspecific variation on *C. arizonica, C. glabra,* and *C. stephensonii* when information about families and populations was included in the analyses. With these findings the authors concluded that restricted distribution of these species might reflect the "*lack of genetic variability appropriate to adjusting to alternative habitats and competitive regimes*" (Rehfeldt, 2003). In addition, results from this study agree with the hypothesis that environmental conditions explain current restricted distribution of most Cupressus species.

One evident difference among *Cupressus* species relates to the tolerance of seedlings to shade conditions and the ability of certain species to continuously disperse seeds and recruit. Most *Cupressus* species in California seem to have shade intolerant seedlings, which would explain higher recruitment on bare ground than in areas with presence of other species, as reported by several authors (Wolf 1948 Armstrong, 1966 Kuhlmann 1986, Lyons, 1998 Cheng 2004). A notable exception to this is *C. sargentii*, which can have a permanent seedling bank even in mature stands where understory light is greatly reduced (Cheng, 2004). In addition to this, *C. sargentii* is one of the few California cypresses less dependent on fire to release seeds (Cheng, 2004). *C. lucitanica*, a cypress widely distributed in Mexico and Central America, also has shade tolerant seedlings and fire-independent seed dispersal (Wolf, 1948). These characteristics together might explain the abundance of both species in their range of distribution. In fact, although other Cupressus species do not depend on fire to release seeds (*C. bakeri, C. macrocarpa, C. montana, C. abramsiana*), seedlings are shade intolerant which probably reduces the replacement capacity of undisturbed populations.

Despite that Tecate cypress is not widespread and common in California, it grows well in a variety of conditions, which favors the hypothesis that current distribution of Tecate cypress reflects its low competitive abilities. This species is relatively easy to grow in controlled conditions (Wolf, 1948), it has moderately to high resistance to cypress canker (Wagener, 1948), and it can grow in a wide variety of soils (Stottlemeyer and Lathrop, 1980). In fact, Buns and Sauer (1992) documented the successful introduction of 6400 Tecate cypress seedlings of San Gabrielino Mountains. Zeddler et al. (1984) explored the factors that could explain the restricted distribution of this species to particular soil types. They concluded that interspecific competition more than specific soil requirements are probably responsible for its aggregated and patchy distribution. These authors reported negative competitive effects of a native forb (*Helianthemum scoparium*) on Tecate cypress even on soil from areas naturally dominated Tecate cypress. This result concurs with previous field observations that suggested that the restricted distribution of several *Cupressus* species reflects the overall poor competitive ability of these trees (Wolf, 1948; Armstrong, 1978, Stottlemeyer and Lathrop, 1981). Nevertheless, Zeddler (1984) also concluded that seedling survival improves after the first growing season when Tecate cypress seedlings grow taller than its competitors.

The case of Tecate cypress and *C. guadalupensis* is particularly intriguing given that although taxonomically close, both species seem to have strikingly different recruitment patterns. Part of the problem is the lack of consistent information regarding seed release mechanisms and requirements of seedling establishment. Throughout the literature Tecate cypress is described as a species that requires fire to release seeds. Nevertheless, this description is mainly based on observations of post-fire population densities and there is no quantification of recruitment without fire. Armstrong (1966) reported that cones open without fire when they are dry and Zedler (1986) suggested cones open under intense summer heat, although in regular conditions they might take several years to open. In this sense, although postfire recruitment might guarantee population recovery, there is no real evidence that populations without fire have negative population growth.

The perception that lack of recruitment on Tecate cypress is mostly due to altered fire conditions contrasts with perceptions on *C. guadalupensis*. Studies of *C. guadalupensis* in Guadalupe Island, Mexico suggest this species recruits without fire. In fact, the main concern regarding the conservation status of this species is not the lack of fire or the high frequency of it, but limited recruitment due to goat browsing (De la Luz et al., 2005 Rosas-Escobar et al., 2008). Results from exclusion experiments demonstrate that recruitment is possible in unburned populations (Junak et al., 2005) although Santos del Prado and Peters (2005) stated that no recruitment had been observed. Further research is required to validate current perceptions on recruitment potential of both species, and to elucidate whether ecological differences between these species can be attributed to local adaptation, despite that some authors even consider them as varieties of the same species.

Table 4. Reproductive traits of selected *Cupressus* species

Species Name	Common Name	Maximum Height (m -Bannister, 1980)	Maximum diameter (cm Bannister, 1980)	Expected growth rate in height (Bannister, 1980)	Height at maturity (Johnson, 1970)	Age of production of first ovulated cones (years)	Cone opening	Seeds per cone (Fargon,)
C. forbesii	Tecate cypress	10.44	45.72	6.35	4.5-9	5 7	cones open inefectively without fire (Zedler, 1986)	100-115
C. guadalupensis	Guadalupe cypress	22.62	137.16	7.62	12-20		recruitment without fire is possible	100-115
C. goveniana		26.1	45.72	5.08				
C. goveniana var. abramsiana	Santa Cruz Cypress	26.1	45.72	6.35		6	release seeds when dry	60-120
C. goveniana var. goveniana	Gowen cypress	8.7	20.32	6.35	6-18	4?	cones open with fire (Vogl and Armstrong, 1988)	60-140
C. goveniana var. pygmaea	Mendocino cypress	52.2	254	6.35	9-46	4		130 (Johnson, 1970)
C. sargentii	Sargent cypress	27.84	91.44	5.08	9-23	5 6	regeneration without fire	90-110
C. bakeri	Modoc cypress	29.58	91.44	5.08	9-15	6 7 regular production therafter	regeneration without fire	40-85
C. macrocarpa	Monterrey cypress	26.1	182.88	8.89	18-27	10	regeneration without fire	110-150
C. lusitanica var. lusitanica	Mexican cypress	26.1	45.72	7.62	30		after mature	65-85

Species Name	Common Name	Maximum Height (m -Bannister, 1980)	Maximum diameter (cm Bannister, 1980)	Expected growth rate in height (Bannister, 1980)	Height at maturity (Johnson, 1970)	Age of production of first ovulated cones (years)	Cone opening	Seeds per cone (Fargon,)
C. lusitanica var. benthamii		22.62	60.96	7.62				65-85
C. macnabiana	MacNab cypress	13.92	91.44	5.08			remain unopen after maturity/Fire dependent/rarely reseeds without fire	60-105
C. arizonica	Arizona Cypress	34.8	91.44	6.35	8-5		cone remain close but may open after mature (armstrong 1948). Contradictory evidence from Vogl 1965 and Armstrong 1948	75-120
C. arizonica var. stephensonii	Cuyamaca cypress	17.4	71.12	3.81	9-15	14?		100-125
C. arizonica var. nevadensis	Piute cypress	26.1	45.72	5.08	6-15		Cones open after fire	80-100
C. arizonica var. montana	San Pedro Martyr cypresss	12.18	66.04	5.08			inmediate after maturity	60-70

C. arizonica var. glabra	Smooth arizona cypress	22.62	45.72	6.35	6-12			75-110
C. nootkatensis		52.2	609.6	6.35				

Reproductive ecology and recovery after fire

One of the features of *Cupressus* species that separates them from other genus in the family is that most New World cypresses show some degree of serotiny (Little, 2006). Thus, seed release events are tight with fires that promote cone opening and seed dispersal. Despite this general trend within the genus, variability across species is less clear. There are not estimations of the degree of serotiny for each species, and it is not clear whether serotiny is a trait varying across species, across populations, or even across individuals. This gap in the information parallels the lack of information on recruitment without fire and seeling requirements for succesfull establishment, already discussed. Nevertheless, there is relatively good information on some reproductive traits, such as number of seeds per cone and height and age at maturity; although, there is no evident correlation between this traits and conservation status of these species (Tables 1 and 3).

Lack of reliable reproduction information limits any estimation of optimal fire regimes. California cypresses might mature as early 4 years of age like in *C. goveniana*, which suggests population recovery after fire might be possible even at intense fire frequencly. For Tecate cypress, Zedler (1995) suggests cone production increases until 90 years of age, while Dunn (1986) estimates peak cone production at 40 years of age. When this information is combined with density dependent mortality Dunn (1985 and 1986) concluded that optimal fire regime for this species is between 35-40 years. Thus, more important than age or height of first reproduction is an accurate estimation of peak cone production, and little information is known regarding this trait.

In contrast with this narrow tolerance to higher and lower fire frequencly of Tecate cypress, *C. sargentii* might recovers well from fires as frequent as 20 years or as sporadic as 100 years (Neeman et al 1999). *C. sargentii* is apparently less fire dependent than other California cypress (*C. macnabiana* –Cheng, 2004). Neeman et al (1999) suggest that higher population resilience for this species in contrast with Tecate cypress might be due to higher growth rates under more favorable conditions. Other factors that could explain this difference are continuous recruitment after fire and higher adult survival to fire (Wolf, 1948).

Fire dependency of seedlings is not correlated with population status of California cypresses as suggested by the cases of Tecate cypress and *C. sargentii*. *C. macnabiana* is described as a species highly dependent on fire (Wolf, 1948) but given its abundance its conservation status is of lower risk (Table 1). In contrast, *C. abramsiana* is vulnerable due to small and fragmented populations, despite fire is not required to release seeds (Lyons, 1998). More information is required to reliably assess the consequence for populations of interactions with fire.

III. Conclusions

Throughout this document we have presented several studies that described taxonomic, biogeographic, and ecological characteristics of *Cupressus* species growing in California. The main objective of this review was to explore any possible correlation between ecological traits of the different *Cupressus* species and their conservation status. Current distributions of *Cupressus* species are probably the result of factors acting at different spatio-temporal scales. On one hand, several studies that support the hypothesis that environmental factors strongly control and have influenced present and past distribution of California cypresses. Paleobotanical evidence points out that past climatic characteristics could have favored a more widely distributed common ancestor of contemporary California cypresses (Axelrod, 1996). Cypress fossils found in areas that are currently warmer and drier support this argment. Current trend toward warmer and drier environmental conditions implies that the elevation range with optimal conditions for population persistence might have shifted to higher elevations, while total area necessary shrunk. Thus, current conservation efforts for Tecate cypress should effectively integrate the potential response of this species to current trends on Climate change.

In addition to paleobotanical evidence, present and previous experiments on seedling growth highlight the importance at the local scale of moisture and temperature on successful seedling survival (Wolf, 1948; Bannister, 1980; Rehfeldt, 2003; Harrington, 2004). In particular, Tecate cypress is described as a species that can grow in a variety of soil conditions but which distribution will be limited in areas with extreme high and low temperatures, and low moist conditions (Minnch, 2007; Rehfeldt, 2003). Other observational studies interpret current distribution of *Cupressus* on ridges, wester slopes, and ravines as evidence of moisture requirements for these species (Posey and Goggans, 1967; Armstrong, 1978; Brown 1982; Minnich, 2007). Despite previous studies suggesting current distribution of *Cupressus* species might reflect specific soil requirements, we found strong evidences to conclude that *Cupressus* species in general, and Tecate cypress in particular, can grow in a variety of soil conditions, and they are highly tolerant to poor soils. Tecate cypress can be considered a versatile species with high tolerance to poor developed soils with low nutrient levels (Sottlemeyer and Ansary, 1980; and Zedler et al. 1984). More over, successful cultivation of Tecate cypress and successful introduction of this species in areas outside its native range demonstrate the feasibility of reintroducing this species to areas where it has vanished, and expanding its current range of distribution.

Although most *Cupressus* species are described as poor competitors, there are very few studies that explicitly address these issues. Most observations suggest negative effects of competitors on seedling establishment (Armstrong, 1966 and 1978; Lyons, 1998; Neeman et al., 1999); for example, effects of the invasive species (*Genista monspessulana* and *Cortaderia jubata*) on *C. abramsiana* (Lyons, 1998); or overcompetition of cypresses by other conifers (Minnich, 2007). Nevertheless, there is only one study that explored the effects of competition, which concluded poor competitive ability of Tecate cypress (Zedler et al. 1984). This lack of information highlights one of the major gaps in our knowledge of Tecate cypress. It is essential for conservation and restoration puposes to accurately estimate the true competitive ability of Tecate cypress; specially in the light of increasing prensence of exotic species.

Cupressus species are described as trees requiring bare ground for successful establishment and fire for seeding. Most authors interpret the copious establishment on post-fire areas as evidence of such a requirement. Nevertheless, there is little information about variability in serotony across species, populations, or individuals, and importance of recruitment in the absence of fires. In addition, we found no evident trends on autoecological traits with respect to conservation population status, especially in traits related with reproduction and seedling recruitment. Reproductive traits such as germination percentage, seeds per cones, height or age of first reproduction are highly variable, which limits any formal analysis. Considering the potential negative effects of changing fire regimens on population stability of California cypresses, our main recommendation for future research is to focus on the study of reproduction traits that can be used to estimate true risk and potential recovery after fire. In particular, it is important to estimate the relationship between cone production and age or size of individuals, as well as seed viability changes over time.

Considering the status of knowledge on Tecate cypress life history traints, and the urgency to developed efficient management strategies for this species, our main recommendation for future research are:

1) Integrate current climate change trends into strategic planning of management and restoration of Tecate cypress populations.

2) Explore competitive abilities of Tecate cypress not only with respect to native species commonly found around Tecate stands, but also with respect to exotic species.

3) Investigate the variability in serotony across populations, or individuals and estimate the relationship between cone production and age or size of individuals, as well as seed viability changes over time

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